

**THE APPLICATION OF THE LOAD-VELOCITY RELATIONSHIP AS  
A MEANS OF DICTATING RESISTANCE TRAINING INTENSITY**

**Harry Francis Dorrell**



**UNIVERSITY OF  
LINCOLN**

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**Director of studies:** Dr Thomas I. Gee



## Abstract

The vast majority of resistance training programmes utilise traditional percentage-based loading methods to dictate and modify training intensity over time. These methods rely on predetermining load based on pre-training strength assessments. While such methods are widely used within both the applied and research environments, percentage-based loading approaches do not factor in current levels of fatigue or athlete readiness to train. A prospective alternative advocated as a means to address such issues, involves the collection of concentric repetition velocity and the documented relationship it has with relative load. While such velocity-based methods are becoming increasingly popular, little consideration has been given to the applied nature of such approaches when compared to traditional percentage-based methods. As such, the main purpose of this thesis was to explore the efficacy of adopting a velocity-based loading approach when compared to traditional percentage-based loading during a strength and power intervention.

Before such an aim could be addressed, the method of collecting and reporting concentric repetition velocity in an applied environment would need to be explored. For this reason, **Study 1** examined the validity and reliability of a commercially available linear positional transducer when compared to an integrated motion capture and piezoelectric force plate setup. Regression analysis resulted in  $R^2$  values of  $> 0.85$  for all variables excluding deadlift mean velocity ( $R^2 = 0.54-0.69$ ), demonstrating high levels of agreeability between devices with minimal exclusions. Furthermore, the presence of low to moderate typical error (0.6-8.8%) across all variables assessed demonstrates the sensitivity of the device. Collectively the novel data within this study provides sufficient evidence that the GymAware PowerTool can be used to measure kinetic and kinematic outputs in a resistance trained

population across a range of widely practiced movements. These findings were significant in providing confidence in the methods used to obtain such variables.

**Study 2** explored the impact of integrating a velocity-based loading approach into a six-week training intervention when compared to traditional percentage-based loading. Within this study velocity was recorded in real-time and used to dictate training load based on a pre-established generalised group-based load-velocity profile. The findings of this study demonstrated the potential benefit of adopting such an approach. Participants within the velocity group obtained similar or statistically greater improvements in measures of strength and power than the percentage-based group (velocity vs. percentage: back squat: 9.3% vs. 8.4%; bench press: 8.4% vs. 4.0%; strict overhead press: 6.5% vs. 6.2%; deadlift: 6.4% vs. 3.0%; countermovement jump: 5.0% vs. 1.0%). Additionally, participants within the velocity-based group completed significantly ( $p < 0.01$ ) less total training volume throughout the intervention.

While the findings from Study 2 demonstrate the potential significance of adopting a velocity-based loading approach over traditional methods, the presence of large individual differences between participants load-velocity relationships warranted further investigation. As such, **Study 3** explored the efficacy of two differing velocity-based loading approaches over a strength and power training intervention. Participants were allocated to either an individual- or group-based velocity intervention, whereby load was dictated based either on the individual or generalised group data, respectively. While no significance interaction was reported between training groups, the individualised group did result in a greater magnitude of change (individual vs. group: back squat: 9.7% vs. 7.2%; countermovement jump: 6.6% vs. 4.3%; static squat jump: 4.6% vs. 4.3%; standing broad jump: 6.7% vs.

3.4%), larger effect sizes, and either the same or stronger magnitude-based inferences across all assessed variables.

Taken collectively, the research studies that are presented within this thesis provide preliminary data supporting the use of velocity-based loading interventions when working with trained individuals. It would appear that adopting a velocity-based loading approach may offer additional benefits to already trained participants both with regards to significant improvements and less required training volume. Furthermore, the trivial improvements witnessed following an individualised approach may suggest a greater potential for adaptation when compared to a generalised group-based approach. As such, this thesis serves to demonstrate that monitoring velocity within resistance training offers a more objective and sensitive approach to prescribing training load than traditional percentage-based approaches.

## **Publications arising from this thesis**

### **Chapter 4.0**

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### **Chapter 5.0**

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## Nomenclature

Abbreviation	Full word/phrase
1-RM	One repetition maximum
ANOVA	Analyses of variation
BM	Body mass
CI	Confidence interval
CMJ	Countermovement jump
COM	Centre of mass
CV	Coefficient of variation
EMG	Surface electrode electromyography
ES	Effect size
FVR	Force-velocity relationship
GA	GymAware attachment site
GAP	GymAware Pro
GLVP	Group load-velocity profile
GPT	GymAware PowerTool
GRF	Ground reaction force
ILVP	Individual load-velocity profile
LPT	Linear position transducer
LVP	Load velocity profile
MCV	Mean concentric velocity
PBT	Percentage-based training
RIR	Repetitions in reserve
RM	Repetition maximum
RPE	Rating of perceived exertion
SBJ	Standing broad jump
SD	Standard deviation
SEE	Standard error of the estimate
SEM	Standard error of the mean
SSJ	Static squat jump
SWC	Smallest worthwhile change
T	Trial
TE	Typical error
V20	20% velocity drop-off
V40	40% velocity drop-off

<b>Abbreviation</b>	<b>Full word/phrase</b>
VB	Velocity-based training
VM	Virtual midpoint

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# **1.0 Introduction**

## 1.1 Introduction

A fundamental determinant of successful performance across numerous sporting activities is the ability to produce high force outputs in the shortest time period possible (Haff & Nimphius, 2012). As resistance training is widely considered the best approach to improve force generating capacity, the optimal configuration of training variables within traditional periodisation has received considerable attention within research (Fry, 2004; Kraemer & Ratamess, 2004; Mangine et al., 2015b). While all of the acute training variables contribute to the resultant physical adaptations, research has highlighted the importance of training volume and intensity in such endeavours, specifically the amalgamation of sets, repetitions, and relative load (Kraemer & Ratamess, 2004; Schoenfeld, 2010; Williams, Trewartha, Cross, Kemp, & Stokes, 2017). Further research has revealed that while all training variables are important considerations, the relative load applied is critical when targeting maximal strength and power output, particularly with more experienced athletes (Fleck & Kraemer, 2014; Schoenfeld, 2013; Schoenfeld et al., 2014). As such, the manner in which load is dictated and modified over time has received considerable attention in current research (Banyard, Tufano, Delgado, Thompson, & Nosaka, 2018; González-Badillo & Sánchez-Medina, 2010; Hackett, Cobley, Davies, Michael, & Halaki, 2017; Helms, Cronin, Storey, & Zourdos, 2016; Reynolds, Gordon, & Robergs, 2006).

Traditional loading methods traditionally utilise pre-training one repetition maximum (1-RM) testing to dictate relative load over progressive sessions (Seo et al., 2012; Stone et al., 2000). Training load is generally prescribed within relative zones (i.e. maximal strength  $\geq$  85% 1-RM), enabling specific adaptations to be targeted (Harries, Lubans, & Callister, 2015b, 2016). In order to facilitate progression, load will either be modified by standardised absolute increments (i.e. 2.5 kg), or through

athlete perception methods such as rating of perceived exertion (RPE) or repetitions in reserve (RIR; Helms et al., 2016; Zourdos et al., 2016b). Coaches will use the athlete's subjective assessment of the difficulty of the session or individual set, combined with the achieved to target-repetitions ratio to systematically dictate load alterations facilitating progression / regression (Helms et al., 2016; Zourdos et al., 2016b).

While such methods are commonly utilised within applied strength and conditioning, and are considered reliable means of altering load, contemporary research has questioned the efficacy of such approaches (Banyard et al., 2018; Jovanović & Flanagan, 2014; Verdijk, Van Loon, Meijer, & Savelberg, 2009). Concerns around the arbitrarily prescription of load based on variable 1-RMs have been highlighted. As training progresses and athletes gain strength, pre-training 1-RMs will no longer be representative of a true maximum, with this being more apparent in novice athletes (Jovanović & Flanagan, 2014). As such, load prescription may not optimise the training stimulus, potentially compromising subsequent physiological adaptations. To overcome this, an athlete may complete additional 1-RM assessments, however these are time consuming and can lead to unnecessary fatigue during a training cycle (Jovanović & Flanagan, 2014). Additionally, altering load based on subjective athlete feedback may lead to between subject / session inconsistencies due to training experience / understanding (Hackett et al., 2017; Hackett, Johnson, Halaki, & Chow, 2012). While athletes with a greater training experience have been shown to be able to reliably predict RIR and thus make appropriate load alterations, the efficacy of such methods has been questioned, especially with novice athletes (Mann, Thyfault, Ivey, & Sayers, 2010). Therefore, a method allowing objective load prescription and modification could benefit the



athlete and augment the adaptations witnessed, reducing the chance of suboptimal training sessions.

A prospective alternative, which has received considerable attention in recent years, involves the collection of mean concentric lift velocity (MCV) and the proposed correlation it has with relative load (González-Badillo & Sánchez-Medina, 2010; Sánchez-Medina & González-Badillo, 2011a). As repetitions within a set continue, a participant will be unable to maintain MCV output. Furthermore, providing maximal concentric effort is applied during a given repetition, the attained MCV data can be plotted against relative intensity, resulting in a curvilinear relationship. Referred to as the load-velocity profile (LVP), this relationship has been shown to be attainable for numerous multi-joint movements including overhead press, bench press, and back squat (Balsalobre-Fernández, García-Ramos, & Jiménez-Reyes, 2018a; González-Badillo & Sánchez-Medina, 2010; Sánchez-Medina, González-Badillo, Perez, & Pallarés, 2013). González-Badillo and Sánchez-Medina (2010) first established the LVP for bench press, demonstrating the strength and robustness of the curve ( $R^2 = 0.98$ ) even after six weeks training and significant strength increases. The results validate the use of such LVPs and demonstrate the stability of the documented relationship irrespective of fluctuations in maximal strength. Such findings have the capacity to change the way in which load is prescribed, allowing more objective alterations to be made over time.

As LVPs have been shown to be stable, even after significant increases in strength (González-Badillo & Sánchez-Medina, 2010), it is postulated that the associated equation of the line can be used as a means to check the relative intensity of a given load (Banyard, Nosaka, Vernon, & Haff, 2017b; Sánchez-Medina, Pallarés, Pérez, Morán-Navarro, & González-Badillo, 2017). Research has demonstrated that the

rearranged equation and known variables (attained MCV) can be used to estimate current relative loading irrespective of a known 1-RM (Conceição, Fernandes, Lewis, González-Badillo, & Jiménez-Reyes, 2016; Sánchez-Medina et al., 2017). It is therefore proposed that manipulating load based on MCV and the LVP will offer greater specificity to training than the otherwise adopted methods (Banyard et al., 2018). Such methods would take the athlete's current strength and fatigue levels into account, allowing a more dynamic and sensitive approach to load prescription (Banyard et al., 2018). Both positive and negative load alterations would be based on objective data, which in turn could lead to greater witnessed physical adaptations, while reducing unplanned levels of fatigue by limiting unnecessary repetitions and over / under prescribed loading.

To date, limited literature is available on the uses of such methods. Research has focused primarily on maximal velocity lifting at a given percentage 1-RM, as opposed to manipulating the load based on the achieved MCV data (González-Badillo et al., 2015; González-Badillo, Rodríguez-Rosell, Sánchez-Medina, Gorostiaga, & Pareja-Blanco, 2014; Negra, Chaabene, Hammami, Hachana, & Granacher, 2016). While maximal velocity lifting has been shown to be effective at improving strength and power across varied populations, it does not utilise the relationship documented between MCV and relative load (González-Badillo et al., 2015; González-Badillo et al., 2014). Load prescription is still generally prescribed based on pre-training 1-RM, and thus provides no insight into the athlete's current readiness and ability to train.

Only one study exploring such loading methods is currently available within the literature (Banyard et al., 2018). Banyard et al. (2018) explores the impact of utilising a velocity-based loading approach on the acute kinetics and kinematics of the back

squat when compared to traditional percentage-based methods. The data presented demonstrates how utilising a velocity-based loading approach can lead to a significant reduction in mechanical stress (time under tension) and total required repetitions. Furthermore, the velocity-based loading groups produced significantly greater peak and mean velocities, and comparable force and power outputs. While the data only reflects a single session, the reported outcomes could translate over longitudinal programming, potentiating greater physiological adaptations.

## **1.2 Thesis aims**

The purpose of this thesis was to investigate and draw conclusions and practical applications regarding the use of MCV as a means of monitoring and manipulating training load. In order to facilitate this a number of research questions have been raised, which in turn have led to the development of a series of thesis aims and experimental studies.

- 1. Can the GymAware PowerTool be used to track barbell displacement during commonly utilised multi-joint movements?***
- 2. Does the method of differentiation used by the GymAware calculate valid and reliable outputs?***

Firstly, it is imperative to assess the validity and reliability of a commercially available device with the capacity to monitor and report MCV in real-time. To date limited literature pertaining to such a problem is available, of which the majority have drawn conclusions from inadequate comparisons (Drinkwater, Galna, McKenna, Hunt, & Pyne, 2007a). Such a study would provide confidence in any subsequent research involving MCV as a load dictating variable and enable the research to be

conducted within an applied strength and conditioning environment, strengthening the subsequent practical applications.

***3. Can training load be dictated in real time based on mean concentric velocity?***

***4. Does dictating load via mean concentric velocity monitoring lead to significantly greater improvements in measures of strength and power than traditional percentage-based methods?***

Once such a study has been completed, the applied uses of MCV as a load dictation tool will be assessed over a training cycle. Initial research will address this concept in comparison to a widely used load prescription method such as percentage-based loading. As previous literature has shown the LVP to be stable both between and within participants (González-Badillo & Sánchez-Medina, 2010), this study will explore the commonly utilised method of grouping LVP data together and using only the calculated mean as opposed to the individual LVP data of each participant. This method reduces the time constraints of such an approach, thus strengthening the transferability into the applied world.

***5. Can individualising load alterations based on individual load-velocity profiles lead to significantly greater improvements in strength and power?***

***6. Are individual load-velocity profiles viable within applied strength and conditioning?***

The final data collection will draw upon the individual differences associated between participants LVPs and explore the efficacy of utilising these as opposed to group-based means. Such an approach is yet to be explored within the literature, as group-based LVPs have been shown to be sufficient at encompassing the majority of data points (González-Badillo & Sánchez-Medina, 2010; Sánchez-Medina et al., 2013). While this is the case, the differences in LVPs witnessed between similarly trained athletes needs to be explored (Balsalobre-Fernández et al., 2018a) as this may provide greater sensitivity within load alteration and thus augment the adaptations witnessed.

## **2.0 Literature Review**

## **2.1 Preface**

The purpose of this chapter is to review the current body of literature relating to velocity-based resistance training approaches that aim to enhance muscular strength and power. Particular emphasis is placed upon the development and application of velocity monitoring devices, and how these have become integrated within traditional training practices. The relationship between relative load and velocity will then be reviewed, before exploring the literature pertaining to the creation and implementation of various velocity monitoring strategies. Finally, the literature concerning the impact of integrating a velocity-based approach to isoinertial resistance training will be explored. The collation and review of this literature will allow a comprehensive understanding of velocity monitoring and manipulation within resistance training practices.

A continuous search (initiated in September 2015) from the earliest record up to and including December 2018 was carried out using the following electronic databases: MEDLINE, PubMed, Google Scholar, and SPORTDiscus. The search strategy combined any number of the following terms in various combinations: 'tempo' OR 'speed' OR 'velocity' OR 'power' OR 'strength' OR 'weightlifting' OR 'weight lifting' OR 'weight-training' OR 'weight training' OR 'resistance-training' OR 'resistance training' OR 'resistance exercise' OR 'strength-training' OR 'strength training' OR 'power-training' OR 'power training' OR 'velocity based' OR 'velocity-based' OR 'percentage based' OR 'percentage-based' OR 'periodisation' OR 'periodization'. Titles and abstracts of the retrieved articles were individually reviewed. Studies with abstracts that did not provide sufficient information were retrieved for full-text evaluation. The corresponding authors of articles that were potentially eligible were contacted for any missing data or clarification of data presented.

## **2.2 Resistance training**

### **2.2.1 Introduction to resistance training**

The term resistance training is well documented throughout sport, health, and medical literature as a means to promote a wide range of desirable physical adaptations. While the term is often used interchangeably with weight training and strength training, the definition remains constant; referring to the completion of movements against an externally applied load (inclusive of body mass) during fixed- or free-movement patterns (Kraemer & Ratamess, 2004; Stone, Stone, & Sands, 2007). The effectiveness of resistance training relies on the design process having appropriate theoretical underpinning, directly influencing the design process. While a number of theoretical models exist, the most commonly employed approach is based on research by Kraemer (1983a; 1983b), termed the 'acute variable model'.

Within the original concept of this model, resistance training programming was based upon the simultaneous manipulation of four key training variables including, intensity (load), exercise selection, rest duration, and exercise order (Kraemer, 1983a). It was also postulated that the number of sets completed for each exercise was important, as well as ensuring the repetitions were prescribed with reference to the relative intensity (Kraemer, 1983b). Continuous exploration of this model led to the further inclusion of repetition velocity, concluding the manipulatable elements to seven (Kraemer & Ratamess, 2004). Since its inception, the contribution and optimal combination of these training variables has received considerable attention within the literature (Ahtiainen, Pakarinen, Alen, Kraemer, & Häkkinen, 2005; González-Badillo, Gorostiaga, Arellano, & Izquierdo, 2005), however, to date no one approach for optimal outcomes exists due to the variable elements of athletic success.



### *2.2.1.1 Physiological adaptations to resistance training*

Depending on the programme design and overall amalgamation of the acute training variables, resistance training in various forms has the capacity to enhance a range of functional outputs (Gentil, Fisher, & Steele, 2017; Kraemer et al., 2002; Kraemer & Ratamess, 2004; Schoenfeld et al., 2014). These improvements in functional strength, power, and / or muscular endurance are directly related to the physiological adaptations occurring as a result of the training stimuli (Deschenes & Kraemer, 2002).

Within the initial stages of resistance training, the functional adaptations widely reported are primarily due to neurological adaptation as opposed to changes in contractile properties of the muscle (Balshaw et al., 2017; Buckthorpe, Erskine, Fletcher, & Folland, 2015). Literature has demonstrated significant increases in strength as early as two weeks into programming, despite no reported muscular hypertrophic changes (Folland & Williams, 2007; Jenkins et al., 2017; Moritani, 1979). In addition, some research reports no significant increases in muscle cross-sectional area until six to eight weeks of continuous training (Kubo, Ikebukuro, Yata, Tsunoda, & Kanehisa, 2010; Staron et al., 1994), suggesting the witnessed strength improvements are a product of neurological adaptation. These adaptations are theorised to include greater synchronisation and recruitment of motor units, improved rate coding, augmented inter- and intra-muscular coordination, and greater reflex potentiation (Balshaw et al., 2017; Balshaw, Massey, Maden-Wilkinson, Tillin, & Folland, 2016; Crewther, Keogh, Cronin, & Cook, 2006; Folland & Williams, 2007; Häkkinen, 1989; Tillin, Pain, & Folland, 2012).

While an array of literature supports the notion of such neural improvements, the methodologies available to confirm such findings is somewhat limited. To date,

supporting evidence measuring neural activity consequent to resistance training is derived almost exclusively from surface electrode electromyography (EMG; Balshaw et al., 2017; 2018; Ullrich et al., 2015). Whilst these methods provide an insight into the electrical activation of skeletal muscle, ratifying the proposed increases in neural drive, the technique is limited in that it cannot distinguish between individual motor unit recruitment. Specifically, while an increase in neural activity can be highlighted, this can be the product of both an increased recruitment of higher threshold units, or increased firing rate of already recruited units (Deschenes & Kraemer, 2002; Enoka & Duchateau, 2017). Despite a lack of clarity surrounding the specific neural adaptation, research has demonstrated that increased electromyographic output of a muscle translates to increased force output, confirming the impact of such adaptations (Balshaw et al., 2016; Behrens et al., 2016; Calatayud et al., 2015; Ema, Saito, & Akagi, 2018).

Beyond these initial stages of resistance training, specifically succeeding the preliminary neural phase of adaptation, the continued development in strength is widely demonstrated as a product of increased muscle cross-sectional area (Schoenfeld, Peterson, Ogborn, Contreras, & Sonmez, 2015b; Schoenfeld et al., 2014). As training progresses, the neural contribution to strength development is reduced, with further increases primarily attributed to morphological changes such as increased muscle cross-sectional area, facilitating a greater force potential during a given movement (Balshaw et al., 2017; Mangine et al., 2015b; Schoenfeld, 2010). It is suggested that at this stage, relative intensity plays a critical role in continued strength development. Research has demonstrated that high intensity (70-80% 1-RM) resistance training results in greater strength adaptations in previously 'resistance trained' participants (Jenkins et al., 2015; Schoenfeld et al., 2015b) when compared to lower load training (< 70% 1-RM). This has been attributed to the

relationship witnessed between relative load and force production. Greater forces are required to move heavier loads, resulting in increased recruitment of higher threshold motor units, promoting desirable adaptations in strength (Häkkinen, Alen, & Komi, 1985; Jenkins et al., 2015).

This muscular growth or hypertrophy is observed as a marked increase in the synthesis and accretion of contractile proteins, occurring within the whole muscle (< 10%) and independent myofibres (25-35%) (Deschenes & Kraemer, 2002). In addition to an increase in contractile proteins and overall muscle cross-sectional area, research has demonstrated how prolonged resistance training facilitates fibre type transition, ultimately leading to increases in muscular output potential (Adams & Bamman, 2012; Wilson et al., 2012). Most commonly demonstrated within the type II sub-types of muscle fibres, these fibre transitions are frequently witnessed as a conversion from type IIb to type IIa (Mitchell et al., 2012; Schoenfeld et al., 2015b; Staron et al., 1994). Interestingly, while the previously discussed hypertrophy of myofibres occurs across all fibre types, type IIa fibres do demonstrate a greater rate of change (Adams & Bamman, 2012; Folland & Williams, 2007). Thus, resistance training not only facilitates a positive shift in type IIa fibre ratio, increasing force output potential, but due to an increased potential for hypertrophic change with these fibres, further exemplifies the strength-based adaptations due to fibre specific hypertrophy (Adams & Bamman, 2012; Schoenfeld et al., 2015b; Schoenfeld, Wilson, Lowery, & Krieger, 2016b).

Interestingly, following prolonged training interventions (>30 weeks), it is proposed that continued development in strength is due to a secondary phase of neural adaptation (Balshaw, Massey, Maden-Wilkinson, Lanza, & Folland, 2018). Displayed within the later stages of strength development, researchers have

demonstrated that despite a reduction in witnessed morphological adaptations, muscular strength continues to increase (Ogasawara, Yasuda, Ishii, & Abe, 2013). Such findings potentially account for the continued increases in force output and ultimately muscular strength exhibited by those with extensive training backgrounds. During such training periods, focus shifts to optimising movement quality and intermuscular coordination by increasing the technical aspect of required movements (Fleck & Kraemer, 2014).

#### *2.2.1.2 Functional adaptations to resistance training*

As previously mentioned, the adaptations witnessed as a result of resistance training are largely dependent on the manipulation of the acute training variables over time. Muscular endurance, maximal strength, muscular hypertrophy, and increased power output are all common exploits of such training approaches, targeted through subtle changes within overall programme design (Bird, Tarpenning, & Marino, 2005; Fleck & Kraemer, 2014; Holm et al., 2008; Schoenfeld, Ogborn, & Krieger, 2017b). While a range of adaptations can be targeted specifically, some of which will be more pertinent to successful performance, muscular strength is widely advocated as a determinant of success for a range of athletes (Beattie, Carson, Lyons, & Kenny, 2017; Hermassi et al., 2018a). This is predominantly due to the fact that as a performance variable it facilitates more specific training and conditioning, acting as an initial base layer for additional development, while contributing to a positive transfer to performance (Andersen, Andersen, Zebis, & Aagaard, 2010; Bourgeois, Gamble, Gill, & McGuigan, 2017; Comfort, Haigh, & Matthews, 2012; Hermassi et al., 2018a). For example, while lower body power, or more specifically rate of force development, may be a key determinant of success for a given athlete (demonstrated through vertical/horizontal jumping or sprinting), research has demonstrated that in order to optimise such

adaptations, an athlete must first be sufficiently trained (i.e. optimal power development occurs with a 2 x body mass back squat; Haff and Nimphius, 2012; Ruben et al., 2010; Wisløff, Castagna, Helgerud, Jones and Haff, 2004). As such, regardless of maximal force output being a key variable for performance, it is widely focused on within the literature as a method of augmenting athletic performance.

### **2.2.2 Periodisation for strength**

Maximal strength is defined as the maximum amount of force a muscle or muscle group can generate in a single voluntary contraction (Zatsiorsky & Kraemer, 2006). While the optimal configuration of the acute training variables for targeted improvements such as maximal strength is still widely explored, research has confirmed that the manipulation of these variables significantly alters the magnitude and type of resultant adaptation (Kraemer & Ratamess, 2004). Manipulation of these acute training variables allows multiple adaptations to be targeted on a session by session basis. However, in order to continually stimulate targeted adaptation over an extended time period, resistance training programmes must be progressive in nature, working towards an overarching goal (Rhea & Alderman, 2004; Williams, Toluoso, Fedewa, & Esco, 2017). This led to the development and exploration of traditional periodisation.

Often referred to as planned, progressive overload, periodisation encompasses the systematic manipulation of the acute training variables over prolonged time periods (Evans, 2019; Stone, O'bryant, Garhammer, McMillan, & Rozenek, 1982). The overall aim of such an approach is to provide the optimal training stimulus for a given performance output, while limiting the risk of overtraining / fatigue (Turner, 2011). Within the literature, two main models of periodisation exist; linear periodisation, referring to a gradual shift between volume and intensity over a given training period

(Prestes, De Lima, Frollini, Donatto, & Conte, 2009a; Prestes et al., 2009b; Stone et al., 1982), and non-linear periodisation, whereby volume and intensity are alternated with greater frequency (Poliquin, 1988; Rhea, Ball, Phillips, & Burkett, 2002b; Simão et al., 2012b). Regardless of the model adopted, the programmed shift between volume and intensity is achieved through manipulation of the previously mentioned acute training variables, specifically a progression from general to more specific tasks over time (Turner & Comfort, 2017).

Irrespective of the overall periodisation approach adopted, the principle phases of training will likely remain the same (

**Table 1).** Training will initiate within the preparatory phase, made up specifically of general physical training and sport-specific physical training, before progressing into the competitive phase in the later stages of periodisation (Bompa & Haff, 2009). The purpose of the general physical training phase is to prepare the athlete for future workloads, specifically improving their physical work capacity, neuromuscular functioning, and technical ability. Within the sports-specific physical training phase, while the goal is similar, the development of physical capacity is done so to replicate the physiological profile and demands of the sport/event (Zatsiorsky & Kraemer, 2006). During the subsequent competitive phase, the focus is on the maintenance of the previously developed components and conditioning.

**Table 1.** Principle phases of traditional periodisation (adapted from Turner and Comfort, 2017).

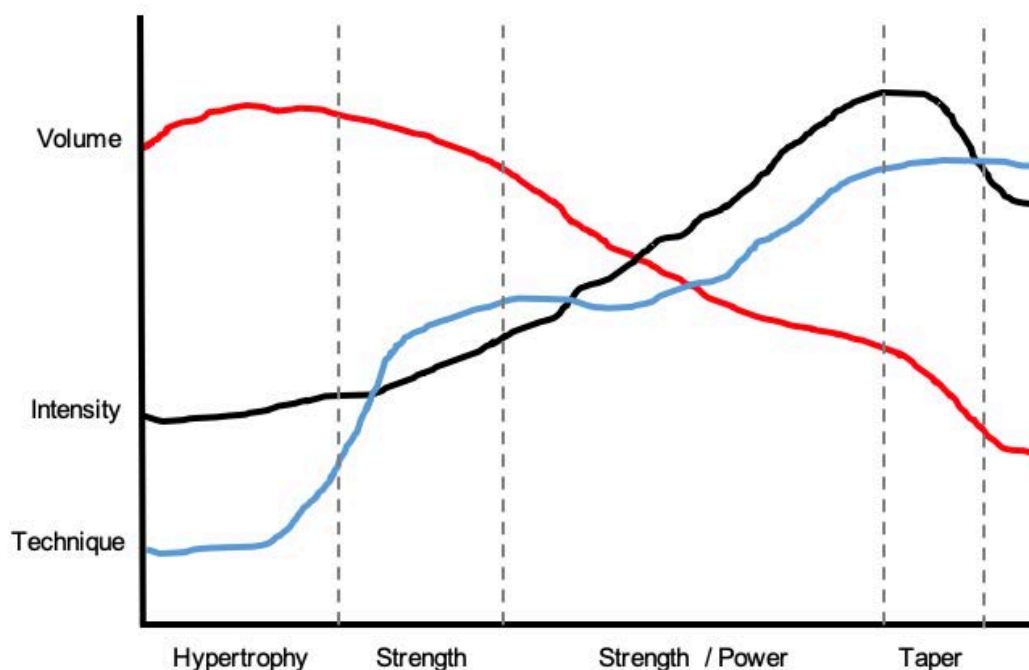
Training phase	Preparatory phase		Competitive phase
	GPT	SSPT	
<b>Objective</b>	Increase work capacity	Develop sport-specific	Maintain physiological conditioning
	Increase neuromuscular function	physical work capacity	
	Improve technical ability		

\* GPT: general physical training; SSPT: sport-specific physical training

With specific reference to strength training, the linear model (Figure 1) divides the overall programme into blocks, phases, or periods, referred to as macro- (9-12 months), meso- (3-4 months), and micro-cycles (1-4 weeks) (Harries et al., 2015b; Rhea et al., 2002b). Training begins with a high volume, low intensity focus, targeting increased muscular cross-sectional area, endurance, and improved neural function (Harries et al., 2015b; Prestes et al., 2009a; Rodrigues et al., 2018). This is generally achieved by combining high repetitions per set and shorter rest periods, with exercises selected and ordered to provide adequate stress and recovery with low technicality (Hartmann, Bob, Wirth, & Schmidtbleicher, 2009; Plisk & Stone, 2003). As the programme develops, the focus shifts to force production and muscular strength by decreasing volume while simultaneously increasing relative intensity. At this stage, multi-joint compound movements become more prevalent within the exercise selection, with the aim of generating maximal force throughout each set. This is achieved through a combination of high relative loads, low repetitions per set, and longer rest periods, enabling force output to be maintained (Fleck & Kraemer, 2014; Kraemer & Ratamess, 2004; Simão et al., 2012b). For many athletes the final training block emphasises the importance of concentric



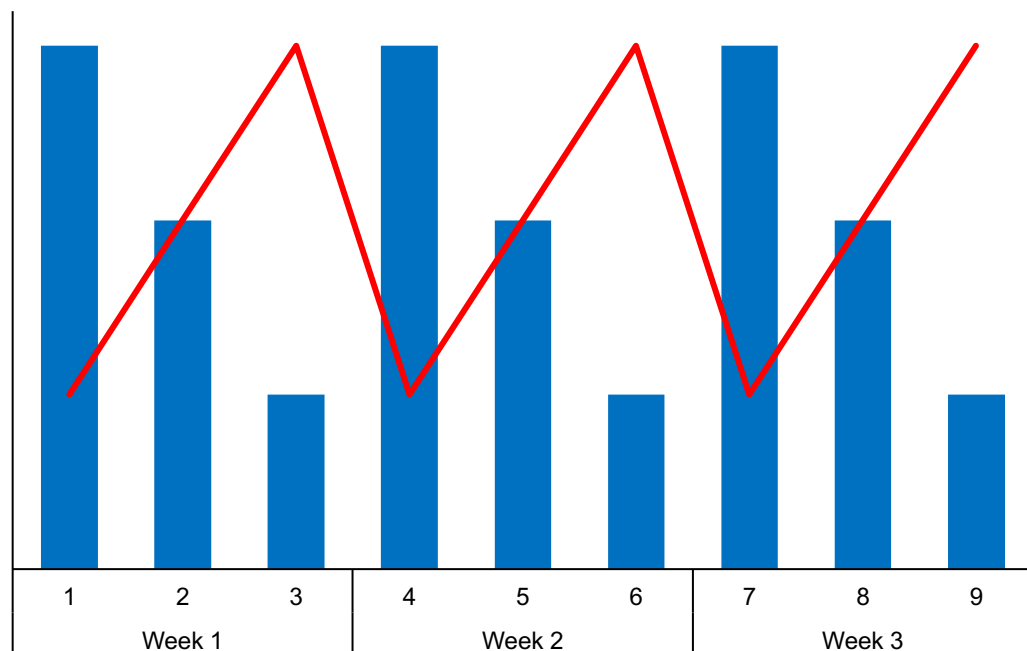
movement velocity and exercise selection and order, focusing on power and rate of force development through moderately loaded, highly technical movements, completed with low total volume (Fleck & Kraemer, 2014; Spreuwenberg, Kraemer, Spiering, & Volek, 2006). However, it is important to note that inherently the specifics within these final stages will ultimately depend upon the important components related to successful athletic performance.



**Figure 1.** Visual representation of linear periodisation, and the shift between volume, intensity, and technical requirement with reference to time and training focus (adapted from Plisk and Stone, 2003).

In comparison, non-linear periodisation (Figure 2), often termed interchangeably with undulating periodisation, utilises frequent changes in training intensity and volume generally over daily (daily undulating), or weekly (weekly undulating) cycles (Buford, Rossi, Smith, & Warren, 2007; Harries et al., 2015b; Rhea et al., 2002b). First advocated by Poliquin (1988), the phases that make up non-linear periodisation are much shorter in duration, providing more frequent alterations in

training stimuli. Such approaches place increased stress on the neuromuscular system as the body is having to constantly adapt to the imposed demands of each varying session. It is this frequent neuromuscular stimulus that is proposed to facilitate positive adaptation over time, while potentially altering the time course of change previously discussed (Buford et al., 2007; Miranda et al., 2011; Prestes et al., 2009b; Zourdos et al., 2016a). With particular reference to advanced lifters, it is suggested that such approaches are more conducive to positive strength gains as the greater frequency of change stimulates later stage neural adaptations (as previously discussed; section 2.2.1.1).



**Figure 2.** Representation of training volume (bar) and training intensity (line) fluctuations within non-linear periodisation.

While the adopted periodisation model has the potential to alter the time course and magnitude of resultant adaptations, manipulation of the acute training variables is still fundamental with regards to improving maximal strength (Colquhoun et al.,

2018; Grgic, Schoenfeld, Skrepnik, Davies, & Mikulic, 2018; Simão, De Salles, Figueiredo, Dias, & Willardson, 2012a). It is generally suggested that maximal strength should be targeted via moderate volume ( $\leq 6$  repetitions; 2-6 sets) training sessions, utilising high relative loads ( $\geq 80\%$  1-RM), and long rest periods (2-5 minutes) (Grgic et al., 2018; Lasevicius et al., 2018; Mangine et al., 2016; Schoenfeld et al., 2016a). Utilising such an approach allows sufficient recovery both between and within sessions, facilitating repetitive maximal force output, ultimately potentiating an increased rate of change.

#### *2.2.2.1 Training volume*

While all of the acute training variables previously discussed contribute to the adaptations witnessed, research has shown that relative training volume, a combination of specific acute variables, is critical in determining the type and extent of resulting neuro-physiological adaptations (Kraemer & Ratamess, 2004; Schoenfeld, 2010). Referring to the combination of sets, repetitions, and relative load lifted for a given movement, training volume is well documented as an essential aspect of resistance training programme design (Rhea, Alvar, & Burkett, 2002a; Rhea, Alvar, Burkett, & Ball, 2003). Altering training volume through manipulation of the aforementioned components has been shown to impact upon the bodies nervous, hormonal, metabolic, and muscular systems, ultimately leading to adaptation (Schoenfeld et al., 2015b). As volume is considered multifaceted, this alteration can be achieved through a series of acute programme changes, including the frequency of training, number of repetitions within a set, the sets completed per exercise, and / or the relative load lifted. Research has explored the impact of manipulating these components, highlighting that while all aspects of volume are important, the relative load of a given exercise is critical when targeting specific

adaptations, especially with intermediate / advanced lifters (Kraemer & Ratamess, 2004; Schoenfeld, 2013; Schoenfeld et al., 2014).

#### *2.2.2.2 Loading*

Within resistance training, intensity or load refers to the mass externally added or moved during a given exercise. The neuromuscular system specifically adapts to imposed demands, resulting in desirable adaptations in muscular strength and functional performance (Stone et al., 2007). Since mechanical stress has been suggested to be of critical importance for inducing adaptation, the external load placed upon a participant during training is considered of upmost importance for targeted improvements (Schoenfeld, 2013). Mangine, Hoffman, Fukuda, Stout, and Ratamess (2015a) highlighted that high intensity training produced favourable effects in force and rate of force development when compared to high volume training. The authors conclude that while a wide variety of training volume and intensity strategies may be employed for novice lifters with positive effect, advanced lifters require a more specific training structure. In order to target optimal mechanical stress, heavy loading (> 85% 1-RM), low-moderate volume (3-5 repetitions), and long rest periods (> 3 minutes) appear to be most beneficial to stimulate a greater rate of change (Mangine et al., 2015a). As such, the ability to objectively quantify, assess, and monitor training load based on targeted adaptations is pertinent to the strength and conditioning practitioner when looking to maximise improvements.

While differing methods for determining training load exist, the most common method, traditionally referred to as percentage-based loading, prescribes relative sub-maximal loads from a previously established 1-RM. This method is prevalent within the literature and has been shown to be valid and reliable across a range of populations and different movements (Faigenbaum et al., 2012; Seo et al., 2012;

Verdijk et al., 2009). However, maximal strength has been shown to fluctuate due to biological and psychological variability, fatigue, and readiness to train, and significantly increase / decrease due to continuous training / periods of inactivity (Ben, Latiri, Dogui, & Ben, 2017; Fisher, Steele, Bruce-Low, & Smith, 2011; Knowles, Drinkwater, Urwin, Lamon, & Aisbett, 2018; Perkins, Wilson, & Kerr, 2001). Consequently, if pre-training 1-RM is representative of an atypical performance, positive or negative, prescriptive loads would be heavier or lighter than optimal. Furthermore, even if achieved load is reflective of current strength levels the method of prescribing load based on pre-established 1-RM does not represent an athlete's day-to-day fluctuations in performance. To counter this, a coach may utilise more frequent testing, however the practicality of such an approach is limited due to the time consuming and fatigue inducing nature of such tests (Jovanović & Flanagan, 2014).

Alternatively, an athlete can complete repetitions to failure, or maximal repetitions within a set time period, with a given sub-maximal load. These methods rely on equations enabling calculation of a theoretical 1-RM based on performance (Picerno et al., 2016). While these methods remove the need to take an athlete to their true 1-RM, thus reducing some of the concerns associated with traditional 1-RM testing, there is an increasing body of evidence suggesting that sub-maximally loaded repetitions to failure does not directly relate to muscular strength in the linear relationship proposed (Izquierdo-Gabarren, Expósito, Garcia-Pallares, Sánchez-Medina, et al., 2010; Izquierdo et al., 2006a). Additionally, Jovanović and Flanagan (2014) demonstrated that ~18% difference is present above or below a previously established 1-RM when utilising such equations due to potential daily variability in readiness to train. Furthermore, the idea of taking athletes to muscular failure has been suggested to be counterproductive to sport specific subsequent performance

due to excessive fatigue and mechanical strain (Izquierdo-Gabarren, Expósito, Garcia-Pallares, Sánchez-Medina, et al., 2010; Izquierdo et al., 2006b; Willardson, Norton, & Wilson, 2010). Specifically, Izquierdo et al., 2006b demonstrated that while training to failure resulted in an increase in the number of achievable repetitions completed at a sub-maximal percentage when compared to non-failure training, it also led to a reduction in maximal power output. Additionally, training to failure resulted in reductions in insulin-like-growth-factor, and serum testosterone, as well as increases in cortisol. Such hormones have been identified to influence the morphological and mechanical adaptation to training. The authors conclude that while adopting repetitions to failure may benefit muscular endurance, when aiming for optimal power output, repetitions should be ceased prior to muscular failure.

Additional loading methods designed to facilitate within training load modification, were designed based on the evidence that individuals respond to training stimuli at varying rates and thus could be training with suboptimal loads during a given time period (Zourdos et al., 2016b). Collectively referred to as autoregulatory loading, these methods offer real time load adjustment based on an athlete's perceived readiness to train (RPE), subjective strength / fatigue levels, RIR, and perceived rate of adaptation (Helms et al., 2016; Helms et al., 2017; Zourdos et al., 2016b). Created to bridge the gap between traditional RPE, and resistance training, RIR employs an athlete's subjective feeling during completion of repetitions to alter certain training variables including load (Table 2). As individuals have been shown to recover and adapt from training stimuli at different rates, it is suggested that utilising an athlete's perception within load prescription may maximise the adaptations witnessed through optimising load selection (Fisher et al., 2011; Mann et al., 2010; Timmons, 2010).

**Table 2.** Resistance specific repetitions in reserve / perceived effort (adapted from Zourdos et al., 2016)

Rating	Description
10	Maximum effort
9.5	No further repetitions, could increase load
9	1 repetition in reserve
8.5	1 - 2 repetition in reserve
8	2 repetition in reserve
7.5	2 - 3 repetition in reserve
7	3 repetition in reserve
5 - 6	4 - 6 repetition in reserve
3 - 4	Light effort
1 - 2	Little / No effort

Mann et al. (2010) explored the impact of autoregulatory progressive resistance training when compared to traditional linear progression over a period of six weeks. Within the linear group, load was pre-determined based upon pre-established 1-RM, with intensity inversely related to volume over time. The autoregulatory groups load was initially based on 1-RM, however fluctuations could occur on a set-by-set basis, based on the previous sets performance and athletes perceived RIR. The results demonstrated greater improvements in the bench press 1-RM, estimated back squat 1-RM, and repetitions to failure with an absolute load (225 lbs) following autoregulatory training when compared to traditional linear training. Further research has explored the efficacy of a RIR approach to optimise loading (Hackett et al., 2017; Hackett et al., 2012; Ormsbee et al., 2017). Within these studies participants completed a given number of repetitions at various relative loads before being asked to vocalise RIR; before continuing with repetitions until failure occurred. The collation of data within these studies demonstrated a strong relationship between an athlete's perceived RIR and their actual RIR (Hackett et al., 2017;

Hackett et al., 2012), and / or concentric movement velocity (Ormsbee et al., 2017), however it was noted that stronger results were obtained from either higher trained athletes, or those closer to failure.

Whilst considered valid and reliable with trained populations, autoregulatory methods adjust load based on subjective input from the athlete or coach, creating potential inconsistencies between athletes and sessions based on understanding, daily motivation, and current perceived fatigue (Hackett et al., 2012; Zourdos et al., 2016b). Furthermore, while these methods facilitate load adaptation within training, they generally require a minimum number of repetitions or sets to be completed prior to accurate interpretation, potentially fatiguing participants prior to load modification (Hackett et al., 2017). Additionally, the relationship between perceived RIR and actual RIR has been shown to increase as the athlete nears fatigue, limiting the efficacy of such approaches when utilising submaximal loading (Hackett et al., 2017; Zourdos et al., 2016b). Therefore, an alternative method able to provide objective load modification in a precise and less demanding manner, could augment adaptations while concurrently limiting training induced fatigue.

A potential alternative, made more accessible with recent advancements in commercially available kinematic measuring devices, utilises the relationship documented between relative load and concentric lift velocity (Conceição et al., 2016; González-Badillo & Sánchez-Medina, 2010). Research has demonstrated that movement velocity, which is dependent on both the magnitude of the load and the voluntary intent to move it (Behm & Sale, 1993), influences neuromuscular stimuli and thus the adaptations consequent to resistance training. This relationship between relative load and concentric velocity, commonly termed the LVP, is generally described via a regression equation producing both a slope and intercept

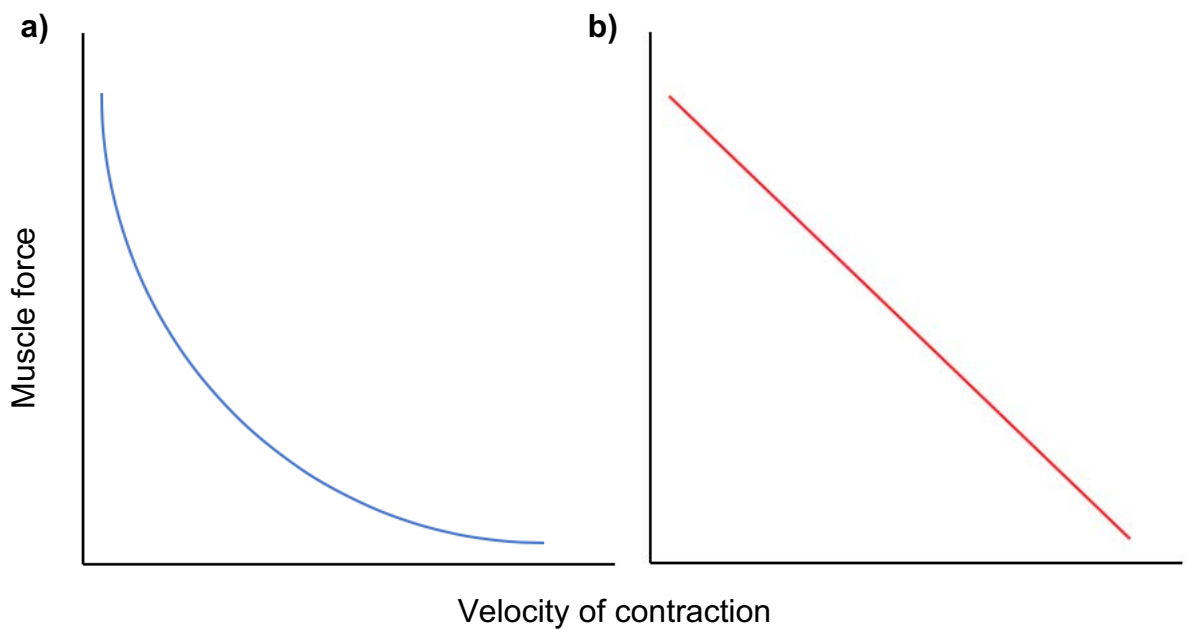


of the line. It has subsequently been demonstrated that upon rearranging this equation, attained velocity can be used as a means of quantifying current relative load, irrespective of previously established 1-RM (Balsalobre-Fernández et al., 2018a; Sánchez-Medina et al., 2013; Sánchez-Medina et al., 2017).

While such methods are becoming increasingly prevalent within contemporary literature, limitations and gaps within currently published data present opportunities for further research to develop and strengthen the current understanding of such approaches. In order to facilitate such an approach, researchers must utilise appropriate equipment, establishing the reliability and sensitivity of the LVP, before exploring the various avenues and uses of repetition velocity.

### **2.2.3 Force-velocity relationship**

The relationship between load and velocity has evolved over time from early research exploring the association between contractile force and contraction velocity of skeletal muscle (Gülch, 1994; Hill, 1983). Commonly demonstrated as an inverse hyperbolic relationship, the force-velocity relationship (FVR) dictates that as muscle shortening velocity increases, the force capabilities of said muscle decrease, and vice-versa (Figure 3) (Rahmani, Viale, Dalleau, & Lacour, 2001). This occurrence is theorised to be due to the time sensitive nature of cross-bridge formation between actin and myosin (Gülch, 1994). Cross-bridge formation between the sliding filaments during a contraction takes a finite amount of time, therefore as shortening velocity increases and filaments slide at an amplified rate, less time is available for cross-bridges to form, impacting upon the force generating capacity of the contraction (Gülch, 1994; Hill, 1983).



**Figure 3.** Relationship between contractile force and movement velocity of a single muscle (a) and across a multi-joint movement or muscle groups (b) (adapted from Jaric, 2015).

While this understanding of the FVR is consistent for single muscle fibres and whole individual muscles, as movements become multi-joint, encompassing a greater range of muscles, the inverse hyperbolic relationship becomes more linear in nature (Figure 3) (Jaric 2015; Rahmani et al., 2001). This is due to a variation in muscle contribution throughout a full range of movement. Varied muscle lengths, fibre orientations, cross-sectional areas, and fibre pennation angles of contributing muscles all impact upon the force-velocity characteristics of a given movement (Samozino, Rejc, Belli, & Morin, 2014). As the associated joint angles fluctuate during movement, the loading upon a given muscle alters, impacting upon the contribution to overall force generation. Furthermore, as angular velocity exceeds the rate of muscle shortening, muscles may “drop-out” of action, while other muscles continue to contribute (Bobbert, 2012; Jaric, 2015; Samozino et al., 2014). This

summation of muscle actions enables velocity decrements to remain consistent over time resulting in the aforementioned linear relationship.

## **2.3 Velocity and resistance training**

### **2.3.1 Velocity monitoring devices**

As strength and conditioning practices have developed, so to have the tools utilised by practitioners to regulate and monitor performance and training variables. The use of linear positional transducers (LPT), accelerometers, and camera systems has become increasingly prevalent within the strength and conditioning environment with the aim of increasing the efficacy of a training session through real-time manipulation of training variables (Benito et al., 2012; González-Badillo & Sánchez-Medina, 2010; Jennings, Cormack, Coutts, Boyd, & Aughey, 2010). As these tools have developed, the ability to prescribe alterations to a given session based on real-time feedback and training variable monitoring has become an important aspect of modern strength and conditioning (Banyard et al., 2018; Mann, 2016; Sánchez-Medina & González-Badillo, 2011a).

Within resistance training specifically, a number of devices utilising different technologies and methods have been developed with the aim of calculating and tracking movement velocity. Traditional acquisition of such variables required the use of three-dimensional high-speed motion capture analysis. While these methods are widely recognised as “gold-standard”, the resource- and labour-intensive protocols and analysis methods, combined with issues relating to applied application, have limited their use within the modern strength and conditioning environment (Askow et al., 2018; Cronin, Hing, & McNair, 2004; Cronin, McNair, & Marshall, 2002). To overcome this, kinematic systems, such as LPTs, are becoming increasingly popular tools for quantifying a variety of outputs associated with

resistance training performance (Argus, Gill, Keogh, & Hopkins, 2011a; Conceição et al., 2016).

#### *2.3.1.1 Linear positional transducers*

Commercially available LPTs consist of an internal spooling mechanism and retractable tethered cord or wire, housed within a magnetically based, battery powered unit. The extension and retraction of the tether (attached to a movable object such as a barbell), causes the spool to rotate, with the velocity of the movement directly impacting upon the rotation speed (Harris, Cronin, Taylor, Boris, & Sheppard, 2010). This in turn creates an electrical signal, proportional to the tether displacement over time. From this time-displacement data, velocity can be calculated, with acceleration, force, and power calculable providing mass of the object and / or athlete are a known entity (Harris et al., 2010).

One such device, which has become increasingly popular within both the applied and theoretical areas of strength and conditioning, is the GymAware PowerTool (GPT) (Argus, Gill, & Keogh, 2012; Beaven, Cook, Kilduff, Drawer, & Gill, 2012; Beckham et al., 2018; Drinkwater et al., 2007b; Weakley et al., 2017). The device has become increasingly prevalent within the literature due to its ability to simultaneously calculate a variety of relative and absolute values during a range of pre-established movements. Furthermore, this data is wirelessly displayed on a tablet or mobile device, removing wired connections as required by other devices. Kinetic and kinematic outputs from the GPT, including acceleration, velocity, power, and force have been assessed across a range of movements including bench press, back squat, seated row, countermovement jump, and power clean (Baker & Newton, 2009; Crewther, Kilduff, Cunningham, Cook, & Yang, 2011b; Cronin, Jones, & Hagstrom, 2007; Drinkwater, Pritchett, & Behm, 2007c). While use of the device as

a measurement tool has increased, data concerning the validity and reliability of the GPT across commonly practiced movements is limited and thus warrants further investigation.

Early research (Drinkwater et al., 2007a) evaluated the validity of the GPT, during free-weight bench press, and Smith-machine back squat and bench throw. Two-dimensional video data were used as the comparative measure, allowing the researchers to explore the validity of both eccentric and concentric peak and mean power outputs of the movements. The relationship between the GPT and video data were analysed using Pearson's correlation, with the standard error of the measurement and coefficient of variation further calculated. The authors expressed high levels of validity based on the correlations reported ( $r \geq 0.97$ ), however the use of manually digitised two-dimensional video analysis, which has an increased risk of both systematic and random error, limits the practical applications of this research.

Further research has sought to limit such error through comparison to "gold-standard" or criterion devices. Contemporary literature investigating the validity and test-retest reliability of the GTP has compared the device to piezoelectric force plates (vertical jump; Crewther et al., 2011b), and purpose built LPT rigs (back squat; Banyard et al., 2017a). While the collection of research has provided greater confidence surrounding the efficacy of the device, a greater understanding of more commonly practiced movements is still warranted. Furthermore, to date no research has compared the measured data from the GPT (displacement) to that of criterion devices (such as three-dimensional motion capture) and has instead focused on the calculated outputs (i.e. velocity, acceleration, force). As the GPT only measures one

variable, with all subsequent data derived from this, research should ensure this variable, while not necessarily linked to performance, is collected with minimal error.

### **2.3.2 Velocity as an acute training variable**

Contemporary LPTs, such as the GPT, are able to simultaneously collect and calculate multiple variables during a single repetition (Banyard et al., 2017a). In some instances, this means practitioners have access to both eccentric and concentric, peak, mean, and propulsive velocity. While mean (average data point), and peak (maximum data point) data are commonly utilised within strength and conditioning practices, propulsive data, referring to the average value between the start of the movement and the moment acceleration is less than gravity ( $-9.81 \text{ m}\cdot\text{s}^{-1}$ ), is less well known. Research has shown that these variables are strongly proportional to the effort / work being performed by the monitored individual (Banyard et al., 2017b; Conceição et al., 2016; González-Badillo & Sánchez-Medina, 2010; Pallarés, Sánchez-Medina, Pérez, De La Cruz-Sánchez, & Mora-Rodriguez, 2014; Sánchez-Medina et al., 2017).

González-Badillo and Sánchez-Medina (2010) demonstrated that while 1-RM may change following periodised training, the mean propulsive velocity associated with any given relative percentage will remain stable. Comparable research produced similar findings, suggesting that all athletes have a stable relative load-velocity relationship that remains constant through periods of training, and furthermore, when working with a group of similar level trained athletes, these individual load-velocity profiles will be comparable (Sánchez-Medina et al., 2013). It has been highlighted that in order for velocity to be used as a monitoring tool for relative load, individuals are required to complete the concentric phase maximally (González-Badillo & Sánchez-Medina, 2010). Early research suggested that voluntary intention

to move a load was as important as the achieved velocity (Behm & Sale, 1993), implying that irrespective of relative load, the willingness to move it maximally influences the specific adaptations witnessed. However, contemporary literature has demonstrated the potential value in velocity-based movements, with methods resulting in increased peak and mean velocity output, and similar force and power production when compared to slower contractions at the same load (Banyard et al., 2018). Therefore, it is apparent that both an individual's intent to lift, and the concentric velocity achieved during a lift, are vital aspects of producing desirable neuro-physiological adaptations, ultimately leading to increased strength and power. Consequently, if the aim of a given session is to improve neuromuscular strength and / or power, the focus should move away from maximal relative loading, and instead focus on maximal concentric velocity during appropriately loaded movements.

When measuring velocity during simple, non-ballistic compound movements (i.e. back squat, bench press, bench pull), the measurement of MCV is considered to better represent the relationship between relative load and individual effort (Jidovtseff, Harris, Crielaard, & Cronin, 2011). A recent study by Banyard et al. (2017b) confirmed that while this is the case during a range of training loads (20-90% 1-RM), when working at 100% 1-RM, concentric peak velocity is more stable than both concentric mean velocity and concentric mean propulsive velocity. While this is an important finding, it is unlikely that individuals will be required to lift at their 1-RM during a training programme, and thus MCV is still widely utilised within the literature (Beaven et al., 2012; Beckham et al., 2018; Sánchez-Medina et al., 2017).

In some instances, researchers have employed mean propulsive velocity over mean velocity in an attempt to remove the effect of the braking phase. Sánchez-Medina

et al. (2013) defined the braking phase within a concentric action as the moment deceleration is greater than deceleration due to gravity alone. In other words, the moment the athlete begins to actively decelerate during the concentric phase before the movement repetition has been completed. The braking phase has been shown to be inversely related to relative load and movement velocity, with lighter external loads requiring a greater duration of braking (Conceição et al., 2016; Pallarés et al., 2014; Sánchez-Medina et al., 2013). This has been linked to the fact that the athlete must maintain technical control regardless of the relative load, and therefore is likely to actively decelerate to stop the bar being released. In some cases, as relative load increases above a given threshold (i.e. bench press load  $\geq 80\%$  1-RM), the braking phase disappears as the athlete is no longer required to actively decelerate during maximal intent repetitions (Sánchez-Medina et al., 2013).

While numerous researchers have highlighted the importance of considering the braking phase within maximal concentric lifting (Conceição et al., 2016; Pallarés et al., 2014; Sánchez-Medina et al., 2013), recent research by Banyard et al. (2017b) and García-Ramos, Pestaña-Melero, Pérez-Castilla, Rojas, and Haff (2018) showed no difference in linearity between mean and mean propulsive velocity with regards to relative load. As such, while both mean velocity outputs produce similar relationships to relative load, the ease of calculation of mean velocity has resulted in this output being the focus within more recent research (Banyard et al., 2018; Weakley et al., 2018; Weakley et al., 2017).

As movements become more ballistic in nature (i.e. Olympic weightlifting movements and derivatives, jumping actions), it has been shown that concentric peak velocity provides a greater consistency over repeated trials (Mann, Ivey, & Sayers, 2015). This has been related to the movement patterns associated with



such movements, and the fact that not all of the movement will be completed with the aim of maximum velocity (i.e. during the first phase of an Olympic lift; Garhammer, 1993). The inclusion of such data will skew the mean result, impacting upon the efficacy of using the mean or mean propulsive as a measure of performance. In contrast, recent work by García-Ramos et al. (2018) highlighted that mean velocity was the most stable predictor of relative load during explosive bench throw. While peak velocity produced lower coefficient of variation between visits, mean velocity and mean propulsive velocity produced stronger linearity with relation to relative load, and greater accuracy as displayed by lower standard error of the estimate. It must be noted, that while the ballistic nature of this movement should lend itself to peak velocity monitoring, the fact the full movement is completed with maximal voluntary intent removes the issues associated with Olympic weightlifting movements and derivatives.

#### *2.3.2.1 Velocity monitoring feedback*

As LPT use has become more prevalent, the software associated with such devices has developed offering more to the strength and conditioning practitioner. The ability to instantaneously track and provide real-time feedback on performance variables such as movement velocity and force is now commonly available (Harris et al., 2010). Such feedback has been shown to promote greater kinematic outputs in participants, alongside increased levels of motivation (Argus et al., 2011a; Randell, Cronin, Keogh, Gill, & Pedersen, 2011; Weakley et al., 2018; Weakley et al., 2017). Research by Argus et al. (2011a) highlighted the importance of verbal kinematic feedback in reducing the decline witnessed across repetitions and sets of explosive bench throw. When feedback was provided, small standardised increases in peak power and velocity (1.8%; 1.3%, respectively) were witnessed when averaged over the sets in comparison to when feedback was withheld. While the acute adaptations

reported were small, this was attributed to the elite training status of the participant group. The authors concluded that the provision of verbal kinematic feedback may result in acute increments in power, ultimately leading to maximised training quality.

Further research by Randell et al. (2011) explored the effects of instantaneous performance feedback (peak velocity) on a power-based testing battery including vertical and horizontal jumps, and short distance sprints (10-, 20-, and 30-m). Following six weeks of training, the results demonstrated moderate to high probabilities of improvement following provision of feedback in the vertical and horizontal jump (45% and 83%, respectively), and 10-, 20-, and 30-m sprints (65%, 49%, and 99%, respectively) when compared to the non-feedback condition. These positive outcomes were attributed to a greater consistency of effort throughout the training period in the feedback group, ultimately leading to greater adaptation potential.

Contemporary research by Weakley et al. (2017) investigated the effects instantaneous visual kinematic feedback had on MCV during the full back squat. Participants either received or were blinded to feedback provided by the GPT on a rep-by-rep bases during a set of ten maximal intent back squats. Feedback resulted in “almost certain” improvements in MCV (7.1%) when compared to the non-feedback condition, with the participants reporting increased motivation, competitiveness, and perceived workload. Further research by Weakley et al. (2018) provided additional evidence supporting the use of feedback in resistance training. Within this study participants received either instantaneous visual or verbal kinematic feedback (MCV reported via the GPT), verbal encouragement, or no feedback during a set of ten maximal intent back squats. Verbal kinematic feedback resulted in the largest increase in MCV between repetitions when compared to the

control group (6.6%), with possible to trivial differences obtained via both visual kinematic or verbal encouragement conditions (6.2%; 6.0%, respectively). The authors concluded that regardless of the manner in which the feedback is provided, visual or verbal kinematic feedback / encouragement can be used to reduce the decline witnessed in MCV during continuous repetitions.

It is worth noting that while the data presented regarding verbal kinematic feedback (Weakley et al. (2018); 6.6%) is noticeably larger than previously reported values (Argus et al. (2011a); 1.3%), this may be explained by the training status of the athletes (elite vs. sub-elite, respectively), the compound movement assessed (bench throw vs. back squat), and / or the variable assessed (peak vs. mean velocity). None the less, the collation of data presented provides sufficient evidence to support the notion of feedback being a valuable addition to resistance training, and specifically VBT. While the specifics surrounding the means by which the feedback is provided requires further research, the provision of feedback has been shown to be an effective method to reducing the decline in concentric velocity and power witnessed as sets and repetitions continue.

### **2.3.3 Load-velocity relationship**

The strength of the load-velocity relationship is commonly reported using the coefficient of determination associated with the line ( $R^2$ ; Sánchez-Medina et al., 2017). As the relationship is not considered truly linear, the majority of research uses quadratic equations such as second order polynomials to achieve this (Conceição et al., 2016; Pallarés et al., 2014; Sánchez-Medina et al., 2013). Providing maximal concentric effort is applied during a given movement, an inverse curvilinear relationship has been reported between relative load and concentric velocity across numerous studies and movements, including bench press, prone

bench row, and back squat (Sánchez-Medina et al., 2013; Sánchez-Medina et al., 2017).

Early research conducted by González-Badillo and Sánchez-Medina (2010) reported a strong coefficient of determination between relative load and concentric propulsive velocity during Smith machine bench press trials ( $R^2 = 0.98$ ). Within this study the LVP of strength trained athletes ( $n = 120$ ) was recorded via LPT during completion of a custom 1-RM test (Table 3). Initial load was set at 20 kg, with participants completing repetitions at 10 kg increments until mean propulsive velocity dropped below  $0.5 \text{ m}\cdot\text{s}^{-1}$ . At this stage smaller increments were used (5 - 1 kg) until 1-RM was achieved. Once all data were collated, the equation of the line was used to extrapolate equated velocity at 5% increments. Following six weeks of resistance training (2-3 sessions/week, 3-5 sets, 4-12 repetitions, 60-80% 1-RM), a subset of the participants ( $n = 56$ ) retested as before. Interestingly, despite a mean increase in strength (9.3%) between trials, a strong relationship was documented between mean propulsive velocity and relative load across all participants. Specifically, no significant difference in MCV at any of the tested relative intensities was reported between time points. The results demonstrate that mean propulsive velocity is a very stable indicator of %1-RM and can be used to monitor relative load independent to maximal strength fluctuations.

**Table 3.** Changes in concentric velocity ( $\text{m}\cdot\text{s}^{-1}$ ) throughout a full bench press load-velocity profile following six weeks training and 9.3% one repetition maximum increase (1-RM) (González-Badillo & Sánchez-Medina, 2010).

% 1-RM	Visit 1	Visit 2	Difference (V1–V2)
30	1.33 ± 0.08	1.33 ± 0.08	0.00
35	1.24 ± 0.07	1.23 ± 0.07	0.01
40	1.15 ± 0.06	1.14 ± 0.06	0.01
45	1.06 ± 0.05	1.05 ± 0.05	0.01
50	0.97 ± 0.05	0.96 ± 0.05	0.01
55	0.89 ± 0.05	0.87 ± 0.05	0.01
60	0.80 ± 0.05	0.79 ± 0.05	0.01
65	0.72 ± 0.05	0.71 ± 0.05	0.01
70	0.64 ± 0.05	0.63 ± 0.05	0.01
75	0.56 ± 0.04	0.55 ± 0.04	0.01
80	0.48 ± 0.04	0.47 ± 0.04	0.01
85	0.41 ± 0.04	0.40 ± 0.04	0.01
90	0.33 ± 0.04	0.32 ± 0.04	0.01
95	0.26 ± 0.03	0.25 ± 0.03	0.01
100	0.19 ± 0.04	0.18 ± 0.04	0.00

Sánchez-Medina et al. (2013) confirmed these findings, while also exploring the LVP associated with the Smith machine prone bench pull. Following a similar protocol as previously described (González-Badillo & Sánchez-Medina, 2010), strength trained athletes ( $n = 75$ ) performed progressive loading tests for both bench press and prone bench pull to establish 1-RM with mean propulsive velocity monitored via an LPT. Strong associations were reported for both bench press ( $R^2 = 0.97$ ) and prone bench pull ( $R^2 = 0.94$ ) between relative load and mean propulsive velocity confirming earlier findings relating to relative load prediction and concentric velocity monitoring. Further research using a similar testing protocol, explored the associated LVP of the Smith machine full back squat (Sánchez-Medina et al., 2017).

Mean, propulsive, and peak concentric velocity were recorded via use of an LPT for 80 strength trained males during an incremental strength test to 1-RM. Following second order polynomial line fitting, strong relationships were reported for both mean and propulsive concentric velocity ( $R^2 = 0.96$ ) with peak velocity showing greater variance ( $R^2 = 0.71$ ). This data not only contributed to movement profiling by exploring the LVP associated with the full back squat, but also demonstrated no difference in statistical output when using mean velocity as opposed to mean propulsive velocity. This finding is particularly important as some commercially available kinematic measuring devices only report MCV as opposed to propulsive velocity due to calculation difficulties associated with this variable.

This combination of data has increased the understanding surrounding the use of LVPs within resistance training. Providing a LVP has been established, it is possible to determine the relative load during a given movement in relation to an athlete's current daily maximum and their MCV (González-Badillo & Sánchez-Medina, 2010; Sánchez-Medina et al., 2013; Sánchez-Medina et al., 2017). Such findings have opened up the possibility of real-time monitoring of relative load, enabling specific adaptations to be targeted, factoring in training fatigue and strength fluctuations, as repetitions, sets, and periodisation progresses. While this is the case, the main limitation of the above research is the use of Smith machine compound movements as opposed to free-weight barbell exercises. This is important to discern due to difference in movement patterns associated with free-weight movements, and furthermore their prevalence within strength and conditioning over Smith machine variants.

To date, only one study has explored the LVP associated with a free-weight movement. Banyard et al. (2017b) explored mean, propulsive, and peak concentric

LVPs associated with the full back squat of 18 resistance trained males. Following an initial 1-RM assessment, each participant completed three repeated visits enabling reliability of the LVP of a free-weight movement to be assessed. The results highlighted that peak concentric velocity was highly reliable across all loads tested, with both mean and propulsive concentric velocity highly reliable across all assessed loads excluding 100% 1-RM (mean propulsive velocity: intra-class correlation coefficient = 0.66, coefficient of variation = 18.0%, effect size = 0.10, standard error of the estimate = 0.04 m·s<sup>-1</sup>; mean velocity: intra-class correlation coefficient = 0.55, coefficient of variation = 19.4%, effect size = 0.08, standard error of the estimate = 0.04 m·s<sup>-1</sup>). Furthermore, the results demonstrated that use of second order polynomial line fitting is reliable between visits. The consolidation of LVP data presented confirms that an irrefutable relationship is present between MCV and relative intensity. The confirmation of such a relationship makes it possible for practitioners to determine the relative intensity incurred by an athlete during training with loads ranging from 30 to 95% of 1-RM.

#### *2.3.3.1 Load-velocity profiling*

In order to successfully integrate concentric movement velocity monitoring into a resistance training programme, the practitioner must first establish the LVP associated with the athlete(s). The kinetics and kinematics associated with commonly practiced multi-joint compound movements has been shown to differ, resulting in key variations in the load-velocity relationship reported. Table 4 demonstrates the LVP associated with three commonly practiced multi-joint compound movements.

**Table 4.** Load-velocity profiles ( $\text{m}\cdot\text{s}^{-1}$ ) associated with commonly practiced multi-joint barbell movements (1, Sánchez-Medina et al., 2013; 2, Pallarés et al., 2014).

<b>% 1-RM</b>	<b>Bench press <sup>1</sup></b>	<b>Prone bench pull <sup>1</sup></b>	<b>Back squat <sup>2</sup></b>
30	1.29 ± 0.08	1.50 ± 0.11	1.40 ± 0.09
35	1.20 ± 0.08	1.42 ± 0.11	1.34 ± 0.09
40	1.11 ± 0.07	1.35 ± 0.10	1.28 ± 0.09
45	1.02 ± 0.07	1.28 ± 0.10	1.21 ± 0.09
50	0.94 ± 0.07	1.20 ± 0.10	1.14 ± 0.09
55	0.85 ± 0.07	1.13 ± 0.10	1.07 ± 0.08
60	0.77 ± 0.07	1.06 ± 0.09	1.00 ± 0.08
65	0.69 ± 0.06	0.99 ± 0.09	0.93 ± 0.08
70	0.61 ± 0.06	0.92 ± 0.09	0.85 ± 0.08
75	0.53 ± 0.06	0.85 ± 0.08	0.74 ± 0.08
80	0.46 ± 0.05	0.79 ± 0.08	0.67 ± 0.08
85	0.38 ± 0.05	0.72 ± 0.07	0.61 ± 0.09
90	0.31 ± 0.05	0.65 ± 0.07	0.54 ± 0.09
95	0.24 ± 0.04	0.59 ± 0.06	0.45 ± 0.10
100	0.17 ± 0.04	0.52 ± 0.06	0.37 ± 0.11

Sánchez-Medina et al. (2013) reported significantly increased mean propulsive velocity for the prone bench pull at all reported percentages when compared to the bench press. While the causes were not assessed within the study, the authors suggested that the changes witnessed may have been the product of neuro-physiological disparities between the associated muscles and movement patterns between the exercises. The longitudinal muscle fibre arrangement and greater fibre lengths present within the primary movers of the prone bench pull (i.e. latissimus dorsi, biceps brachii, brachialis) are associated with faster contraction velocity. In comparison, the shorter fibre lengths and greater pennation angles witnessed within the principal muscles associated with the bench press (i.e. pectoralis major, triceps brachii, anterior deltoid), are linked with greater force generation potential, and thus



slower concentric velocity potential (Lieber & Fridén, 2000; Pearson, Cronin, Hume, & Slyfield, 2009). Izquierdo et al. (2006a) demonstrated larger decreases in bench press concentric velocity when compared to back squat. Furthermore, significantly higher concentric velocity was achieved during back squat repetitions (60 – 75% 1-RM) when compared to the same relative load for the bench press. It is likely that the variation in the LVPs associated with different multi-joint movements is due to distinct differences in the musculature of the primary movers, as well as the associated movement phases of the exercises (Lieber & Fridén, 2000). As such, LVPs should be established for all movements prior to integration into a periodised training regime as opposed to following more general velocity ‘zones’ (Mann, 2016).

The method by which the LVP of a given movement is obtained has yet to be explored within the literature. As such, varied methodologies establishing LVPs across different movements are present in contemporary research, with no evidence supporting a specific approach (Table 5). The generally accepted approach creates the LVP retrospectively from a selection of maximal effort lifts at varying loads. Participants complete a given number of repetitions (inversely related to mean velocity or relative intensity) at a range of increasing loads, generally working to 1-RM. Once all data has been collected, relative load and the respective velocity output (generally mean concentric or mean propulsive) are plotted, before either a linear or polynomial line is fitted (

Figure 4). The equation of the line is then used to retrospectively calculate the velocity associated with a given relative percentage with the error around the line representing an acceptable range.

While these methods are commonly used within the literature (González-Badillo & Sánchez-Medina, 2010; Sánchez-Medina et al., 2013; Sánchez-Medina et al.,

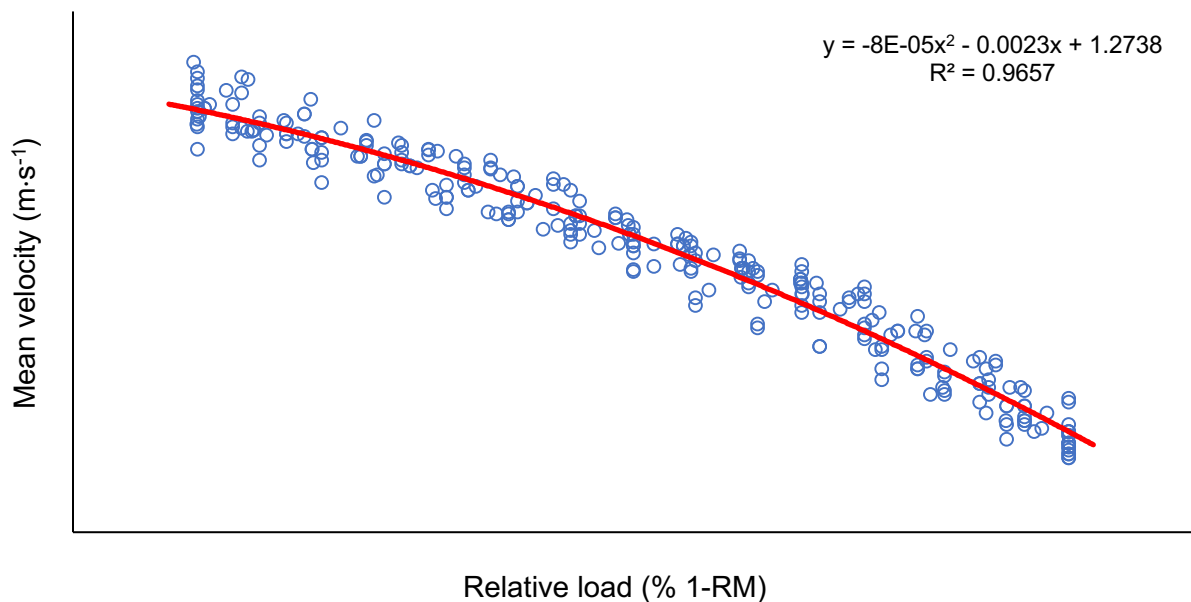
2017), the efficacy of such approaches is disputable. In some instances, absolute load increments are employed irrespective of participants 1-RM (Pallarés et al., 2014). The participants in this study achieved 1-RMs of  $92.2 \pm 11.9$  kg (bench press) and  $100.4 \pm 21.8$  kg (back squat). However, during the LVP data collection, 15 kg increments were employed for part of the collection, equating to ~16 and 15% increases for the bench press and back squat, respectively. A similar protocol employed by Sánchez-Medina et al. (2013) used smaller absolute load increments during LVP establishment (10 kg). However, due to the 1-RMs achieved during testing (bench press:  $90.3 \pm 16.3$  kg; prone bench pull:  $80.2 \pm 11.8$  kg), the increments were still ~11 and 12% for the bench press and prone bench pull, respectively. In both these studies, initial load was set at 20 kg, equating to between 20 – 25% of the maximal load lifted.

When factoring in the velocity at which absolute load increments were decreased (Table 5), participants were only likely to record 5 – 6 sets, in some instances working up to ~90% 1-RM (prone bench pull: Sánchez-Medina et al., 2013) before load increments decreased. When considering that reported LVPs detail the load-velocity relationship over 15 working sets (Table 4), the limited number of actual data points, and their relation to the proposed 5% zone reported is potentially problematic. Therefore, it could be proposed that while more time consuming, greater validity and reliability of data will occur if more sets are recorded at smaller increments, allowing a broader range of data from which to establish the LVP of individual movements

**Table 5.** Methods used to record load-velocity profiles for different multi-joint movements.

Reference	Movement(s)	Method
Balsalobre-Fernández, Marchante, Muñoz-López, and Jiménez (2018b)	Bench press	Initial load ~75% 1-RM, ~5% increments to ~90% 1-RM, attempt 1-RM thereafter
Banyard et al. (2017b)	Back squat	Initial load ~20% 1-RM, repetitions at ~40, 60, 80, 90% 1-RM, 2.5 - 0.5 kg increments thereafter until 1-RM achieved (maximum five attempts)
Conceição et al. (2016)	Back squat	Initial load 20 kg (~20% 1-RM), ~10% 1-RM increments until mean propulsive velocity > 0.5 m·s <sup>-1</sup> , 5 - 1 kg increments thereafter until 1-RM achieved
García-Ramos, Jaric, Padial, and Feriche (2016)	Bench press	Initial load ~20% 1-RM, ~10% 1-RM increments up to ~70% 1-RM (six sets)
González-Badillo and Sánchez-Medina (2010)	Bench press	Initial load 20 kg, 10 kg increments until mean propulsive velocity > 0.5 m·s <sup>-1</sup> , 5 - 1 kg increments thereafter until 1-RM achieved
Loturco et al. (2017)	Bench press	Initial load ~50% 1-RM, ~10% 1-RM increments until 90% 1-RM, ~5% increments thereafter until 1-RM achieved
Naclerio and Larumbe-Zabala (2017)	Bench press	Initial load ~30% 1-RM, repetitions at (~) 45, 50, 65, 70, 85, and 100% 1-RM

Reference	Movement(s)	Method
Pallarés et al. (2014)	Bench press	Initial load 20 kg, 15 kg increments until mean propulsive velocity > 0.5 m·s <sup>-1</sup> , 5 - 2.5 kg increments thereafter until 1-RM achieved
	Back squat	Initial load 20 kg, 15 kg increments until mean propulsive velocity > 0.7 m·s <sup>-1</sup> , 5 - 2.5 kg increments thereafter until 1-RM achieved
Picerno et al. (2016)	Chest press	5 - 6 repetitions at ~50%, 4 - 5 repetitions at ~65%, 3 - 4 repetitions at ~80% 1-RM
	Leg press	5 - 6 repetitions at ~50%, 4 - 5 repetitions at ~65%, 3 - 4 repetitions at ~80% 1-RM
Sánchez-Medina, Perez, and González-Badillo (2011b)	Bench press	Initial load 20 kg, 10 kg increments until mean propulsive velocity > 0.5 m·s <sup>-1</sup> , 5 - 1 kg increments thereafter until 1-RM achieved
Sánchez-Medina et al. (2013)	Bench press	Initial load 20 kg, 10 kg increments until mean propulsive velocity > 0.5 m·s <sup>-1</sup> , 5 - 2.5 kg increments thereafter until 1-RM achieved
	Prone bench pull	Initial load 20 kg, 10 kg increments until mean propulsive velocity > 0.7 m·s <sup>-1</sup> , 5 - 2.5 kg increments thereafter until 1-RM achieved
Sánchez-Medina et al. (2017)	Back squat	Initial load 20 kg, progressive increments until mean propulsive velocity > 0.7 m·s <sup>-1</sup> , 5 - 2.5 kg increments thereafter until 1-RM achieved



**Figure 4.** Example data depicting the load-velocity profile with a second-order polynomial line fitted.

#### 2.3.4 Integrating velocity monitoring into resistance training to control fatigue

Contemporary literature has established a strong relationship between isoinertial resistance training, concentric movement velocity, and neuromuscular fatigue (Pareja-Blanco, Rodríguez-Rosell, Sánchez-Medina, Gorostiaga, & González-Badillo, 2014; Pareja-Blanco et al., 2017; Sánchez-Medina & González-Badillo, 2011a). While numerous definitions of fatigue exist, a recurring observation is an exercise-induced decline in muscular force generating capacity and subsequent decline in movement velocity (Pasquet, Carpentier, Duchateau, & Hainaut, 2000; Sánchez-Medina & González-Badillo, 2011a; Westerblad, Allen, Bruton, Andrade, & Lännergren, 1998). As muscular force potential decreases, continual performance becomes increasingly difficult until eventually, if continued, task failure ensues.

Accompanying this reduced muscular force generating capacity is a visible decline in concentric contraction velocity due to a build-up of metabolic by-products

(Sánchez-Medina & González-Badillo, 2011a). This gradual decrease witnessed in repetition velocity is generally interpreted as evidence of impaired neuromuscular function (Jovanović & Flanagan, 2014). Continued repetitions under fatigue causes a marked disruption in cellular homeostasis, leading to significantly increased blood ammonia levels, indicating accelerated muscular purine nucleotide depletion and simultaneous increases in lactate, ultimately leading to reduced performance and extended recovery times (Pareja-Blanco et al., 2017; Sánchez-Medina & González-Badillo, 2011a). As such, it has been proposed that monitoring concentric velocity may offer a method of objectively limiting training induced fatigue by altering the repetitions prescribed based on the velocity output of those completed (Banyard et al., 2018).

Within contemporary research, the use of specific velocity zones or velocity stops has been advocated as a novel way to facilitate this (Banyard et al., 2018). A velocity zone can be defined as a predetermined range which acts as an indicator of relative load of a given exercise (Mann, 2016). Athletes utilising velocity zones within training are required to complete repetitions within this range to develop specific performance outcomes (i.e.  $\leq 0.5 \text{ m}\cdot\text{s}^{-1}$  for absolute strength; Mann, 2016; Mann et al., 2015). Conversely, a velocity stop is defined as a movement velocity for each repetition, acting as a minimum velocity threshold (Pareja-Blanco et al., 2017). Athletes are required to remain above this threshold throughout all repetitions in an attempt to limit fatigue. Once the velocity stop is passed, repetitions within a given set stop. Research suggests that when used in conjunction, velocity zones and stops may enhance muscular strength and power adaptations while acting to minimise neuromuscular fatigue (Pareja-Blanco et al., 2017).

As such, the monitoring of concentric velocity is advocated as a means to provide a real-time insight into actual training intensity, facilitating load and/or volume alterations prior to athletic fatigue occurring (Pareja-Blanco et al., 2014; Pareja-Blanco et al., 2017; Sánchez-Medina & González-Badillo, 2011a). Such methods have resulted in similar or significant increases in power output, and no significant reduction in achieved maximal strength or force output when compared to more traditional percentage-based approaches (Banyard et al., 2018; Pareja-Blanco et al., 2014). However, to date VBT methods are yet to be compared to a specific maximal strength training regime. Within such programme design, repetitions at or close to failure (1-3 repetitions to failure) are generally employed with near maximal loads ( $> 85\%$  1-RM) (Moss, Refsnes, Abildgaard, Nicolaysen, & Jensen, 1997; Schoenfeld, Grgic, Ogborn, & Krieger, 2017a; Suchomel, Nimphius, Bellon, & Stone, 2018; Tan, 1999). Such methods optimally stimulate recruitment of higher threshold motor units (not recruited with less fatiguing loading strategies) ultimately leading to increased force potential and maximal strength (Suchomel et al., 2018; Tan, 1999; Zatsiorsky & Kraemer, 2006). As VBT methods are advocated as a means of avoiding accumulation of such fatigue (Pareja-Blanco et al., 2017) it could be suggested that such methods will provide a less than optimal stimulus for maximal strength training. However, it is important to discern that while VBT is advocated as a means of limiting fatigue, it does so through optimising loading and associated repetitions, not by limiting the load an athlete works at. Furthermore, until such comparisons are explored, the relationship between such methods is purely hypothetical.

#### *2.3.4.1 Velocity loss and training fatigue*

Recent research has shown that, providing repetitions are performed with maximal concentric effort, monitoring repetition velocity, specifically within-set velocity drop-

off, provides an objective, non-invasive indicator of training fatigue (Sánchez-Medina & González-Badillo, 2011a). It is specifically the last repetitions within a set, in relation to the maximal number of repetitions that could have been completed that contribute the most to metabolic stress and mechanical fatigue (Sánchez-Medina & González-Badillo, 2011a). Padulo, Mignogna, Mignardi, Tonni, and D'ottavio (2012) explored the impact of minimising velocity drop-off by implementing a 20% velocity stop during bench press repetitions. Participants completed repetitions at either fixed pushing speeds (FPS;  $0.45 \text{ m}\cdot\text{s}^{-1}$ ), or self-selected pushing speeds (SPS), at the same relative load ( $\sim 85\%$  1-RM). The FPS group completed repetitions until propulsive velocity dropped below a 20% threshold (i.e.  $0.36 \text{ m}\cdot\text{s}^{-1}$ ), whereas the SPS group completed repetitions until muscular failure. At both the start and end of the intervention the total completed repetitions were significantly less for the FPS group when compared to the SPS group due to the velocity stop (sets, repetitions: FPS:  $7.00 \pm 0.08$ ,  $2.33 \pm 0.52$ , SPS:  $7.98 \pm 0.04$ ,  $7.00 \pm 0.42$  vs. FSP:  $9.00 \pm 0.00$ ,  $3.17 \pm 0.75$ , SPS:  $9.00 \pm 0.00$ ,  $8.33 \pm 1.03$ , respectively). Despite the reduction in total completed volume ( $\sim 62\%$ ;  $p < 0.01$ ), the authors reported significant improvements in maximal strength ( $\sim 10\%$ ;  $p < 0.01$ ) and maximal pushing speed ( $\sim 2\%$ ;  $p < 0.01$ ) for the FPS group only.

Further research by Pareja-Blanco et al. (2017) explored the effects of different concentric velocity stops in the full back squat. Participants completed three sets of the back squat at loads ranging from 70-85% 1-RM. Repetitions were completed with maximal effort and would cease following a concentric velocity drop-off of either 20% (V20) or 40% (V40). The results demonstrated that after eight weeks of training (16 sessions), significant increases in strength (18.0%) and countermovement jump (9.5%) were witnessed in the V20 group, despite completing  $\sim 40\%$  fewer repetitions, and thus  $\sim 36\%$  less total work than the V40 group. In contrast, the V40



group expressed significantly greater increases in muscle cross-sectional area but displayed significantly reduced percentages of the fastest myosin isoform (myosin heavy chain IIb) where this remained unchanged in the V20 group. The authors concluded that while a higher magnitude of velocity loss resulted in greater hypertrophic adaptations, favourable strength and functional improvements were witnessed following a less demanding protocol, despite a reduction in total volume lifted. It is worth noting that with reference to the back squat, a 40% velocity stop allows athletes to complete repetitions very close to that of volatile failure. In contrast, adopting a lower drop-off such as 20% is comparable to performing approximately half of the maximal number of repetitions that could be completed per set (Sánchez-Medina & González-Badillo, 2011a).

As previously mentioned (section 2.2.1.1; 2.3.4), training to, or very close to muscular failure (~40% velocity loss, Sánchez-Medina & González-Badillo, 2011a) has been suggested to lead to a greater recruitment of higher threshold motor units (Suchomel et al., 2018; Tan, 1999; Zatsiorsky & Kraemer, 2006). However, within the above examples, employing a 20% velocity stop resulted in favourable physical adaptations in maximal strength when compared to training at or close to failure. While this is a significant finding favouring velocity-based approaches, it must be acknowledged that in both instances (Padulo et al., 2012; Pareja-Blanco et al., 2017) the comparative group (SPS and V40, respectively) completed significantly greater training volume within the same time period. This accretion of additional training volume would have likely impacted upon the accumulation of athlete fatigue. This additional fatigue, combined with no load taper and the limited time frame between training and testing, may have negatively impacted upon the control group ultimately leading to a reduction in force generating capacity. Irrespective of employing an effective taper, future research may wish to complete additional

testing sessions after longer recovery periods have been given to further understand the potential timeframe of adaptations following a VBT approach. Such findings would strengthen the understanding of how best to implement VBT within traditional periodisation strategies.

Additional research by Cooke (2017), while not exploring the link between velocity loss and fatigue, documented the relationship between MCV, RPE, and RIR (Table 6). Within this study, 58 resistance trained individuals (male: 43; female: 15) completed a custom back squat 1-RM protocol, requiring two repetitions (where achievable) at each increment (10% 1-RM) starting at 30% 1-RM. Participants were required to complete the repetitions with maximal concentric effort, reporting their perceived RPE at the end of every set. This novel data demonstrates the link between two means of controlling within-session fatigue, specifically MCV monitoring and RPE / RIR, further displaying how MCV may offer greater sensitivity in such an approach (Helms et al., 2017; Padulo et al., 2012; Pareja-Blanco et al., 2017; Zourdos et al., 2016b).

**Table 6.** Relationship (mean  $\pm$  SD) between mean concentric velocity (MCV), rating of perceived exertion (RPE), and associated repetitions in reserve (RIR) during a custom back squat maximal strength assessment (adapted from Cooke, 2017).

Intensity (% 1-RM)	MCV ( $\text{m}\cdot\text{s}^{-1}$ )	RPE	Associated RIR
30	$1.06 \pm 0.13$	$1.5 \pm 1.0$	N/A
40	$1.00 \pm 0.12$	$2.0 \pm 1.0$	N/A
50	$0.91 \pm 0.10$	$3.0 \pm 1.5$	N/A
60	$0.82 \pm 0.09$	$4.0 \pm 1.5$	$\geq 6$
70	$0.69 \pm 0.08$	$5.0 \pm 1.5$	$\geq 6$
80	$0.55 \pm 0.08$	$6.5 \pm 1.0$	6 – 2
90	$0.39 \pm 0.08$	$8.5 \pm 1.0$	3 – 1
100	$0.26 \pm 0.06$	$9.5 \pm 0.5$	$\leq 1$

#### 2.3.4.2 Velocity zones and training response

An advantage of VBT approaches advocated within the literature centres on the idea of specificity and training optimisation. Research has shown that the neuromuscular system adapts to the specific demand placed upon it (SAID principle) and thus optimal configuration of training variables is essential (Pareja-Blanco et al., 2017; Spiering et al., 2008). Training at optimal relative intensity, and thus utilising appropriate targeted energy systems, can lead to increased likelihood of positive adaptations, increasing the efficacy of training. The relationship documented between relative load and concentric velocity led the development of specific targeted velocity zones (Table 7). These zones correspond to a range of relative intensities associated with adaptations, providing a general range for training.

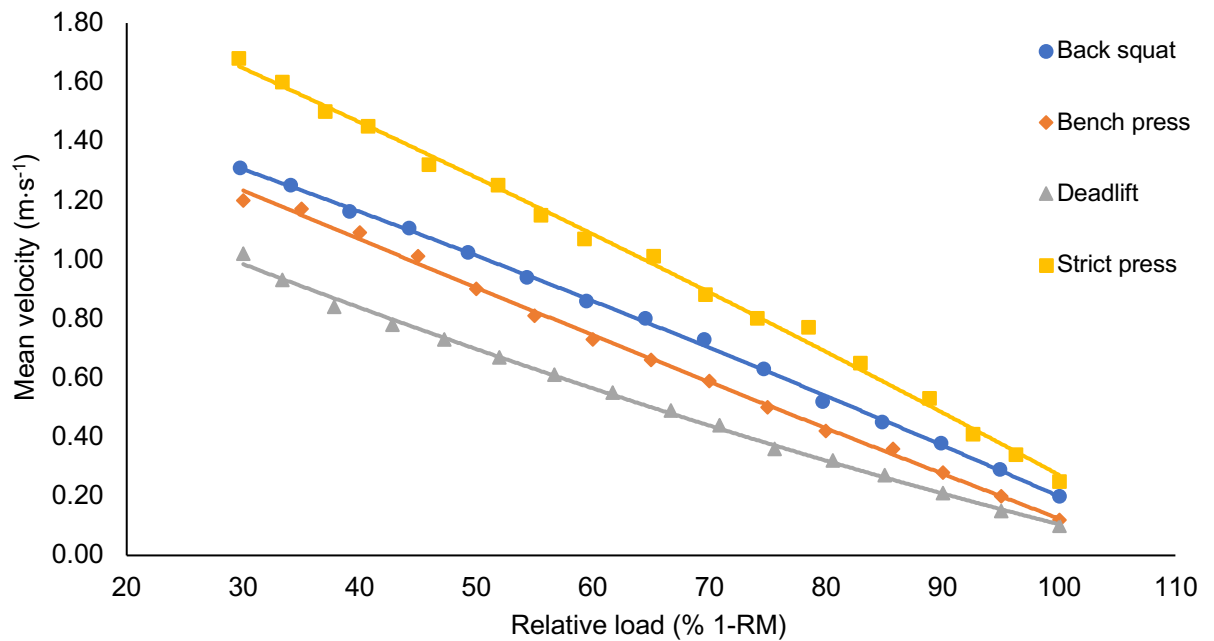
**Table 7.** Velocity zones and corresponding concentric range ( $\text{m}\cdot\text{s}^{-1}$ ) and approximate one repetition maximum percentage (% 1-RM) (Mann et al., 2015).

Velocity zone	Velocity range ( $\text{m}\cdot\text{s}^{-1}$ )	Approximate % 1-RM
Absolute strength	< 0.50	> 80%
Accelerative strength	0.50 – 0.75	65 – 80%
Strength-speed	0.75 – 1.00	45 – 65%
Speed-strength	1.00 – 1.30	25 – 45%
Starting strength	> 1.30	< 25%

The creation of the displayed zones was based on a combination of data exploring the load-power-velocity relationships of various movements in an attempt to provide additional information regarding optimal loading and means to objectify it (Mann et al., 2015). Terms and appropriate load and velocity associations are available for absolute strength, strength-speed, speed-strength, and starting strength within the literature (Jandačka & Beremlijski, 2011; Jidovtseff, Quièvre, Hanon, & Crielaard, 2009; Roman, 1988). While the culmination of such load-velocity ranges is referred to within the literature, the validity of such zones has yet to be explored. Additionally, it is important to discern that the velocity zones associated with commonly prescribed multi-joint resistance exercises (i.e. bench press, back squat, prone bench pull, deadlift) may differ due to key variances in the load-velocity and power-load relationships, as well as distinct differences in the musculature of the associated primary movers (Izquierdo et al., 2006a; Lieber & Fridén, 2000; Sánchez-Medina et al., 2013).

While the above zones (Table 7) offer a general approach to facilitate integration of velocity monitoring into periodised training, it is essential that practitioners first assess the LVP associated with a given movement, specific to their population

group. As demonstrated in Figure 5 and Table 4, differing multi-joint movements produce noticeably different LVPs and thus the associated velocity zones proposed by (Mann et al., 2015a) would result in a less effective loading strategy. The differences witnessed are likely a result of differing movement patterns, muscular architecture, and strength curves (Pearson et al., 2009; Sánchez-Medina et al., 2013). Furthermore, the training status and resistance experience of the participants has been shown to influence the LVP, specifically with strength trained participants at higher intensities / slower concentric velocities (Table 8). A potential explanation pertains to the idea that stronger athletes will be able to push, or 'grind', through the sticking point / region with greater effect (Zourdos et al., 2016b). Defined as the point at which applied force is less than gravity, the sticking region is distinguished as a notable reduction in barbell velocity and power (specifically the first third of the concentric phase of a movement), leading to potential repetition failure (Cotterman, Darby, & Skelly, 2005; Drinkwater et al., 2007a). Due to a greater potential motor unit recruitment, stronger more experienced participants have an increased capacity to overcome the critical joint angle associated with the sticking region and complete the repetition at a lower concentric velocity (Table 8; Zourdos et al., 2016b).



**Figure 5.** Relationship between concentric mean velocity and relative load for four commonly practiced free-weight multi-joint exercises ( $n = 1$ ).

Another method for creating velocity zones utilises the confidence intervals (CI) associated with the reported data, enabling a relative range to be prescribed around a given relative load. This method is becoming more prevalent within contemporary literature as it enables velocity zones to be specific to the athlete(s) and movement(s) assessed, accounting for individual differences (Banyard et al., 2018). Furthermore, it allows a specific velocity range to be calculated around a given relative load, enabling traditional loading methods to employ velocity as a monitoring tool. Providing participants have a similar training experience / relative strength (Table 8), and are being assessed against a standardised protocol, the LVPs recorded can be combined creating a group velocity profile for a given movement (Sánchez-Medina et al., 2013; Sánchez-Medina et al., 2017). Within the literature, the standard deviation (SD) associated with this group profile is then used to

calculate appropriate CIs (generally 95%), acting as upper and lower boundaries of acceptable velocity.

**Table 8.** Mean concentric velocity achieved from different populations (training experience) at one repetition maximum (1-RM) for the full back squat.

Reference	Movement	1-RM (kg) [relative]	Training experience	Velocity at 1-RM (m·s <sup>-1</sup> )
Pallarés et al. (2014)	Smith machine	97.2 ± 16.8 [1.19 ± 0.21]	Resistance trained *	0.37 ± 0.11
Zourdos et al. (2016b)	Free weight	91.2 ± 25.5 [1.14 ± 0.32]	Novice squatters	0.34 ± 0.07
Sánchez-Medina et al. (2017)	Smith machine	107.0 ± 21.5 [1.44 ± 0.22]	Resistance trained	0.32 ± 0.03
Conceição et al. (2016)	Smith machine	124.2 ± 26.6 [1.77 ± 0.38]	Resistance trained	0.30 ± 0.04
Banyard et al. (2017b)	Free weight	142.3 ± 28.3 [1.74 ± 0.21]	Resistance trained	0.26 ± 0.06
Zourdos et al. (2016b)	Free weight	171.9 ± 50.9 [1.87 ± 0.56]	Experienced squatters	0.24 ± 0.04
Helms et al. (2017)	Free weight	202.2 ± 26.4 [2.30 ± 0.30]	Experienced powerlifters	0.23 ± 0.05

\* The training status of participants is as defined by the researchers. In this instance, considering relative strength of the participants, the mean velocity at 1-RM, and the large standard deviation reported, it is likely the participants are novice lifters as opposed to resistance trained as reported.



Sánchez-Medina et al. (2013; 2017) have explored this approach across a range of compound movements including back squat, bench press, and prone bench pull. Following completion of an LVP (Table 4), the SD of the sample population is used to calculate the standard error of the estimate (SEE), allowing CIs to be calculated. However, in both instances the reported CIs are ambiguous due to incorrect calculation or misleading column headings within the data presentation. While the authors have portrayed values representing 95% CIs around the mean values calculated, they have actually reported the CIs around the standard error of the mean, thus showing whether the reported sample data is a representation of the estimated population data. While this information is potentially useful, it does not represent the confidence interval of the data collected, and thus cannot be used as a monitoring tool.

Table 9 illustrates the mean velocity obtained and the CIs (column two and three, respectively; Sánchez-Medina et al., 2017). Column four within the table displays the actual 95% CIs of the mean velocity values reported based on the SEE. As can be seen from the presented data (Table 9), the values reported as 95% CIs are significantly smaller than the actual values calculated, potentially leading to the creation of unachievable mean velocity zones. Furthermore, when reviewing the actual CIs, it becomes apparent that the resultant boundaries of acceptable mean velocity encompasses a large range of relative loads. For example, an athlete achieving a mean velocity output of  $1.07 \text{ m}\cdot\text{s}^{-1}$  could be lifting between 40 – 60% 1-RM. With reference to Table 7, the velocity would suggest the athlete was working on “speed-strength”, however with  $1.07 \text{ m}\cdot\text{s}^{-1}$  potentially being achievable at 60% 1-RM, this would indicate “strength-speed”, and thus warrant different volume and rest strategies. Therefore, it could be suggested that the larger ranges witnessed

remove the specificity associated with the theory behind mean velocity monitoring as a means to regulate load. This limits the efficacy associated with utilising 95% CIs as a means to create velocity zones. While lower CIs may not encompass all of the data, they may offer a more robust approach for individualised velocity zone creation, and therefore warrant further investigation.

**Table 9.** Mean velocity (MV) attained at relative percentages of one repetition maximum (% 1-RM) for the back squat (n = 80), standard error of the mean confidence intervals (SEM; CI; 95%), and associated mean velocity confidence intervals (Sánchez-Medina et al., 2017)

% 1-RM	MV ( $\text{m}\cdot\text{s}^{-1}$ ) *	SEM 95% CI ( $\text{m}\cdot\text{s}^{-1}$ ) **	~ MV 95% CI ( $\text{m}\cdot\text{s}^{-1}$ ) ***
40	1.19 $\pm$ 0.08	1.18 – 1.21	1.07 – 1.31
45	1.14 $\pm$ 0.08	1.12 – 1.16	1.02 – 1.26
50	1.08 $\pm$ 0.07	1.06 – 1.10	0.96 – 1.20
55	1.02 $\pm$ 0.07	1.00 – 1.03	0.90 – 1.14
60	0.95 $\pm$ 0.07	0.94 – 0.97	0.83 – 1.07
65	0.89 $\pm$ 0.06	0.87 – 0.90	0.77 – 1.01
70	0.82 $\pm$ 0.06	0.80 – 0.83	0.70 – 0.94
75	0.74 $\pm$ 0.05	0.73 – 0.75	0.62 – 0.86
80	0.67 $\pm$ 0.04	0.66 – 0.68	0.55 – 0.79
85	0.59 $\pm$ 0.04	0.58 – 0.59	0.47 – 0.71
90	0.50 $\pm$ 0.03	0.50 – 0.51	0.38 – 0.62
95	0.42 $\pm$ 0.02	0.41 – 0.42	0.30 – 0.54
100	0.32 $\pm$ 0.03	0.32 – 0.33	0.20 – 0.44

\* Values reported as means  $\pm$  standard deviation

\*\* Reported as “mean velocity 95% confidence interval” by Sánchez-Medina et al. (2017)

\*\*\* Values are only approximate as the standard error of the estimate was reported to three decimal places

The collation of presented data provides evidence supporting the notion of stopping repetitions within a set prior to repetition failure as a means to limit fatigue (Pareja-Blanco et al., 2017). Furthermore, providing a LVP has been established, the calculation and integration of specific velocity zones may optimise the training adaptations witnessed, while having no negative impact on force accumulation (Banyard et al., 2018). The combination of velocity stops and / or zones provides practitioners with a novel approach to objectively prescribe individualised training volume and load based on daily fatigue, strength fluctuations, and readiness to train. While this method of controlling volume and load is becoming more prevalent within the literature, the effects of utilising velocity within resistance training prescription warrant further exploration. Research should consider the most appropriate way to create velocity zones, and further explore the LVP associated with commonly practiced movements.

### **2.3.5 Velocity-based resistance training**

Research has demonstrated that optimal movement velocity is an important consideration within the design of periodised resistance training programmes (Pareja-Blanco et al., 2017; Sánchez-Medina & González-Badillo, 2011a). This optimal movement velocity has been defined as a prescribed velocity that maximally influences both neural and muscular mechanisms, consequently optimising functional strength and / or power (Behm & Sale, 1993). Furthermore, it is suggested that greater transferable strength and power adaptations are witnessed with athletes when resistance training is similar to that of successful sporting performance patterns. This would suggest that athletes should aim to utilise resistance loads that enable replication of the velocity and acceleration profiles, as well as specific movement patterns associated with successful sporting performance. As previously

mentioned, such practices are widely advocated during the later stages of the preparatory phase, specifically the sport-specific physical training phase, and also the competitive phase (Turner & Comfort, 2017). As such velocity-based approaches may fit within such pre-established training concepts, potentially augmenting the adaptations witnessed when compared to more traditional approaches.

A number of studies have explored the effects of integrating velocity within training interventions, utilising either isokinetic (constant velocity), or isoinertial (constant mass) muscle actions. Isokinetic dynamometry is frequently utilised within research and considered a valid and reliable tool for quantifying movement velocity (Alemdaroğlu, 2012; Drouin, Valovich-McLeod, Shultz, Gansneder, & Perrin, 2004; Teixeira, Carvalho, Moreira, Carneiro, & Santos, 2015). However, it is generally acknowledged that these actions are less specific to actual sporting movements, thus questioning the transferability of results to the applied setting (González-Badillo & Sánchez-Medina, 2010). Furthermore, the labour- and resource-intensive nature of such protocols presents challenge when looking at the applied strength and conditioning environment (Cronin et al., 2004). In comparison, isoinertial (constant mass) resistance training is extensively utilised within the applied setting as it incorporates the nervous systems ability to concurrently activate and coordinate agonist, antagonist, and synergistic muscle groups, and is consequently considered more pertinent to sporting performance (Kraemer & Ratamess, 2004). This, combined with the development of kinematic measuring systems (such as LPTs), has provided researchers and practitioners with a way to quantify velocity outputs during more 'traditional' training methods.

Research exploring the impact of isoinertial VBT is limited, with the majority of studies comparing maximal concentric velocity movements to either deliberate half-velocity movements (González-Badillo et al., 2014; Pareja-Blanco et al., 2014), soccer specific training (González-Badillo et al., 2015; Negra et al., 2016), high intensity / low velocity training (Delecluse et al., 1995), or to no comparative training method (Ramírez, Núñez, Lancho, Poblador, & Lancho, 2015). Early research by Delecluse et al. (1995) investigated the effects nine weeks (18 sessions) of high velocity training had on different phases of the 100 m sprint when compared to high intensity training. The high velocity group elicited significant improvements in overall sprint time as well as all phases of the sprint breakdown assessed (initial acceleration, build-up to maximum speed, maintaining maximum speed). Conversely, the high intensity group significantly improved in the initial acceleration phase only.

González-Badillo et al. (2014) investigated the influence that maximal velocity isoinertial training had on maximal strength when compared to deliberate half-velocity training. Participants completed Smith machine bench press training for six weeks (18 sessions) in a traditional linear progressive design. The results supported the use of maximal velocity training when compared to deliberate half-velocity, demonstrating significantly greater improvements in 1-RM (18.2 vs. 9.7%), as well as mean velocity at light (11.5 vs. 4.5%), and heavy loads (36.2 vs. 17.3%). A similar study completed by Pareja-Blanco et al. (2014) compared the effects of six weeks (18 sessions) of maximal velocity training to deliberate half-velocity training on Smith machine back squat 1-RM. The results demonstrated that training with maximal propulsive velocity in the full back squat leads to significant improvements in 1-RM. No interaction was present between groups, however larger effect sizes were visible

following maximum velocity training when compared to half-velocity training (0.94 vs. 0.54, respectively). Both of these studies concluded that maximal velocity training may provide a superior training stimulus for inducing maximal strength when compared to slower velocity training.

Comparable research by González-Badillo et al. (2015) and Negra et al. (2016) investigated the effects of high velocity resistance training when compared to 'typical soccer training' on a series of performance measures including jumping assessments, maximal strength, and linear speed (5-, 10-, 20-, and 30-m). For both of these studies the intervention group(s) completed a set number of high velocity resistance training sessions a week, supplementary to their soccer training, while the comparative group(s) completed soccer training only. For both studies it was concluded that high velocity resistance training, combined with soccer training, produced favourable adaptations when compared to soccer training only. Positive effects were reported for maximal strength, vertical and horizontal jumps, and short distance sprint performance. Additional research by Ramírez et al. (2015) reported increases in relative and absolute power, force, and velocity output with a fixed external load following a VBT training intervention. Participants ( $n = 18$ ) completed 10 weeks (20 sessions) of high velocity half-squat training with a fixed load ( $\sim 65\%$  1-RM). It was concluded that VBT appears to promote absolute and relative power outputs, however with no comparative group present it is difficult to draw meaningful conclusions from such data.

To date, very limited research exists comparing the effects of VBT to a more traditional percentage-based training (PBT) approach. Banyard et al. (2018) explored the effects of integrating velocity monitoring into traditional resistance

training on the kinetic and kinematic outputs of the free weight back squat. Following completion of a 1-RM protocol and establishment of the LVP associated with the back squat, participants completed four independent training sessions each under a different condition. Mean and peak values for force, velocity, and power were recorded, as well as time under tension, mean and total session work, and mean and total session load. The PBT condition completed five sets of five repetitions at 80% 1-RM as established from the 1-RM test. Participants within the velocity-based loading condition completed five sets of five repetitions at 80% 1-RM, however the intensity was based on their individual LVP. The fixed set velocity condition involved participants completing repetitions for five sets at 80% 1-RM until their mean velocity dropped 20% below a pre-established threshold, or five repetitions were completed. The variable set velocity condition completed a total of 25 repetitions at 80% 1-RM, however during each set as many repetitions as possible were completed until their mean velocity dropped 20% below a pre-established threshold. The data presented demonstrated that the velocity-based loading condition resulted in significantly higher peak and mean velocities throughout the session, combined with significantly lower accrued time under tension when compared to the PBT group. Importantly, no further differences were reported. The results demonstrate how utilising a pre-established LVP to dictate load allows greater movement velocities to be achieved and maintained. Furthermore, the velocity-based loading condition resulted in reduced time under tension and thus reduced mechanical stress, and yet suffered no decline in force and / or power outputs over a traditional PBT approach.

The integration of velocity monitoring into isoinertial resistance-based interventions is still limited, as such the specifics surrounding VBT and strength and power adaptations are not well understood. While there is evidence to support the use of

such protocols, methodological discrepancies between the research designs limit the confidence surrounding the proposed results. Issues such as lack of training variable control, differing training stimulus between groups, participants training experience, use of a Smith Machine as opposed to free-weight movements, undisclosed maturation status of youth athletes, no comparative control group, and / or unreliable velocity collection methods are present throughout (González-Badillo et al., 2015; González-Badillo et al., 2014; Negra et al., 2016; Pareja-Blanco et al., 2014). Furthermore, to date, no research has explored the use of high velocity resistance training to improve strength and power performance when compared to traditional heavy PBT. Based on the available evidence it is difficult to recommend a movement velocity and / or VBT training design that maximises sport specific strength and power performance, thus warranting further research.

### **2.3.6 Proposed adaptations of velocity-based training**

The mechanisms responsible for the aforementioned adaptations witnessed following VBT interventions are currently not well understood. To date, limited literature is available pertaining to the mechanical changes responsible for the adaptations most commonly displayed following isoinertial VBT regimes. It is suggested that a number of positive alterations may be induced by training with maximal concentric velocity under correct loading conditions, including greater recruitment and activation of fast twitch muscle fibres, increased intra-/inter-muscular coordination, enhanced discharge of high threshold motor units, greater tendon-aponeurosis stiffness, augmented rate coding / motor unit firing frequency, and / or positive changes in myosin heavy chain isoform composition (Claflin et al., 2011; Cronin et al., 2002; Jovanović & Flanagan, 2014; Pareja-Blanco et al., 2014; 2017).



Research by Pareja-Blanco et al. (2017) explored how the magnitude of the velocity stop employed (V20 vs. V40) altered the absolute (1-RM, countermovement jump) and mechanical (fibre type composition) adaptations witnessed. Despite completing 40% less repetitions, and 36% less total work, the V20 group (20% velocity stop) attained greater 1-RM strength gains (18.0% vs. 13.4%), and significantly greater countermovement height ( $p < 0.05$ ; 9.0% vs. 3.5%) when compared to the V40 group (40% velocity stop). These adaptations were attributed to the fact a significant reduction in type IIb fibres was reported in the V40 group only. The mechanistic changes reported were theorised to be a result of the V20 group completing significantly less “slow” repetitions than the V40 group as the velocity stop employed was similar to only completing half the achieved repetitions within a set.

Research has demonstrated that training to failure, which has been shown to be similar to training to a 40% velocity stop (Sánchez-Medina & González-Badillo, 2011a), leads to a fast-to-slow fibre transformation (type IIb to type IIa) (Andersen et al., 2005; Andersen et al., 2010; Kraemer et al., 1995; Paddon-Jones, Leveritt, Lonergan, & Abernethy, 2001). As type IIb fibres are considered to be the most powerful, a reduction may lead to less positive transfer to other movements, such as vertical jumping. Furthermore, training to near failure is linked to greater metabolic and mechanical fatigue, potentially impacting on recovery time and subsequent training sessions. Additionally, it is suggested that continuing repetitions while in a fatigued state, and thus at a slower than optimal concentric velocity, may lead to the development of slower firing, more fatigue resistant fibres (Banyard et al., 2018). It is important to discern that the development of slower firing, more fatigue resistance muscle fibres is not a negative occurrence, and in fact is often considered a necessity when looking to optimise hypertrophy and strength phases

in the future, particularly with novice / beginner athletes (Bird et al., 2005; Campos et al., 2002; Chiu & Barnes, 2003; Ewing, Wolfe, Rogers, Amundson, & Stull, 1990). While this is important to consider, numerous researchers have demonstrated the potential benefits of utilising real-time velocity over more traditional volume / intensity strategies, specifically increased velocity output and associated transition to sport-specific actions (Banyard et al., 2018; González-Badillo et al., 2015; Negra et al., 2016; Ramírez et al., 2015). The culmination of such data further emphasises the potential use of VBT within the sport-specific physical training / competitive phases of periodisation.

#### *2.3.5.1 Further considerations*

While limited research is currently available pertaining to the mechanistic changes witnessed following completion of a VBT intervention, data is available which furthers the understanding as to why adopting a VBT based approach may be beneficial. Pareja-Blanco et al. (2014) demonstrated how post exercise blood lactate, ammonia, and uric acid levels were considerably lower following completion of a VBT programme whereby repetitions were stopped based on MCV output. The reduction in metabolic stress and markers of fatigue reported were very similar to that of previous research whereby participants only completed half the maximal number of repetitions achievable (Sánchez-Medina & González-Badillo, 2011a). Additionally, the group completing repetitions with maximal concentric velocity achieved greater back squat 1-RM (18.0% vs. 9.7%; ES: 0.94 vs. 0.54), and a significantly higher countermovement jump (8.9% vs. 2.4%;  $p < 0.05$ ) when compared to the slower velocity group. Taken together, these findings suggest that while maximal velocity training may provide an optimal stimulus for maximal strength and vertical jumping ability, it does so in a manner that avoids the accumulation of

excessive fatigue that could interfere with the development of additional components (Pareja-Blanco et al., 2014). As such, a velocity-based loading approach could be more suited for specific physical preparation and competitive phases of training, within the later stages of periodisation.

Improvements in muscular strength and power are directly related to a number of concomitant morphological and neurological adaptations (Davies, Kuang, Orr, Halaki, & Hackett, 2017). The primary morphological adaptation, muscular hypertrophy, is witnessed as an increase in muscle cross-sectional area as a result of an increased number and size of the associated myofibrils (Schoenfeld, 2013). In comparison, the principle neurological adaptation is reported as an increased motor unit recruitment and / or firing frequency (Carroll, Riek, & Carson, 2001). Despite similar strength increases following both fast and slow contraction training (Pareja-Blanco et al., 2017), and comparable kinematic outputs following VBT in comparison to PBT (Banyard et al., 2018), it is suggested that the adaptations witnessed may be the result of different mechanisms (Davies et al., 2017).

Slower, more traditional PBT, has been shown to result in greater mechanical and metabolic stress through increased time-under-tension, advocated as a key variable in muscular hypertrophy, resulting in greater morphological adaptations (Burd et al., 2012; Schoenfeld, 2013; Schoenfeld, Ogborn, & Krieger, 2015a). In comparison, the faster contraction speed associated with VBT is suggested to provide a better stimulus for the development of neurological adaptation (Behm, 1995). While in theory this may provide a provisional answer to the debate, no literature has currently explored the velocity during traditional percentage-based loading methods

when compared to velocity-based approaches for more than a single session (Banyard et al., 2018), and thus definitive conclusions cannot be drawn.

## **2.4 Summary**

The collation of research and data presented clearly indicate that within resistance training, intensity is more than solely the magnitude of the load (% 1-RM) being lifted. The velocity at which loads are actually lifted has been shown to influence the resulting training effect and adaptations witnessed. Furthermore, as such a strong linear relationship is present between MCV and relative load, research should endeavour to explore the impact of utilising velocity as more than merely a movement outcome, and instead as a potential loading strategy. While contemporary research has begun to explore the idea of using concentric velocity as a means to alter load, to date no research exists comparing this velocity-based approach to a traditionally practiced method such as PBT. Such research would provide meaningful conclusions as to the worth of such methods through direct comparison to a widely advocated training approach.

## **3.0 General Methods**

### **3.1 Preface**

This thesis features three progressive quantitative experimental studies, designed to examine the effect of monitoring and manipulating load, based on MCV, within a periodised resistance training programme. For ease of interpretation the study in chapter four will be referred to as study one, chapter five as study two, and chapter six as study three. The methods described within this chapter are those generic to the majority of these studies, with further information being available within each individual chapter.

Study one explored the validity and reliability of a commercially available linear positional transducer, the GPT, against integrated criterion devices. Following on from this, study two examined the impact of integrating MCV into a periodised resistance training programme as a means to dictate intensity when compared to a traditional percentage-based approach. Load was dictated in real-time through use of a group LVP, whereby all individual LVPs were combined and the mean data used as the prescription tool. The final study explored the individual differences present between individual participants and investigated whether these could alter the proposed adaptations when compared to a group-based approach (as in study two). While both groups completed the same resistance intervention, the velocity-based loading method utilised differed between intervention groups.

### **3.2 Data collection**

For all data collections, the entirety of testing and training took place at the same venue (Human Performance Centre, University of Lincoln), within a specialised laboratory, under the direct supervision of the lead investigator. For each individual study, each participant tested / trained at the same time of the day ( $\pm 1$  hour), and under constant environmental conditions ( $\sim 20^{\circ}\text{C}$ ).

### **3.3 Participants**

Participants recruited for the experimental studies were required to be between the age of 18-40, and free from any musculoskeletal injury. Further to this, all participants had to be currently engaged in resistance training ( $> 6$  months), have previous resistance training experience ( $> 2$  years), be proficient in the required movements being assessed (e.g. back squat, bench press, strict overhead press, conventional deadlift), and not engaged in using performance enhancing drugs. For study one, sex was not specified within the inclusion criteria, due to the explorative nature of the project. Within study one, participants data were only compared within, thus focusing on one sex was not necessary. However, for study two and three only male participants could volunteer due to the deductive study design, and the fact pre-to-post changes have been shown to vary based on sex (Ivey et al., 2000). All participants were recruited from the following sources; University of Lincoln Strength and Conditioning in Sport, and Sport and Exercise Science undergraduate programmes, local specialised weightlifting facilities, and local and University sports clubs via face to face contact and email correspondence. Following provisional volunteering for the study, participants were informed of the procedures, associated risks, and potential benefits, before providing informed consent, and being screened for inclusion.

### **3.3.1 Screening documents**

Prior to completion of any testing / training, participants were given a series of documents and consent forms. The completion of all forms were reviewed by the lead researcher prior to official acceptance onto the data collection, enabling any contraindications to be highlighted. The following forms were standard throughout all studies:

- Participant information sheet (Appendix 1)
- Physical activity readiness questionnaire (Appendix 2)
- Medical history questionnaire (Appendix 3)
- Current activity questionnaire (Appendix 4)
- Informed consent form (Appendix 5)

Once all forms had been completed the participants responses were reviewed and put through a standardised inclusion criteria check sheet (Appendix 6).

### **3.3.2 Ethical approval**

Prior to any contact with potential participants each study required approval from the University of Lincoln institutional ethics committee, in line with the Helsinki Declarations for research with human volunteers.

## **3.4 GymAware PowerTool**

The GPT (Kinetic Performance Technology, Canberra, Australia) is an LPT designed specifically for measuring athletic performance during resistance training. The GPT is comprised of an internal spooling mechanism and tethered cord, housed within a magnetic unit. The extension and retraction of the tether (attached directly to the athlete or weightlifting bar) alters the position and speed of the rotations of



the spool. As the spool rotates, real-time time-displacement data is logged, facilitating the calculation of both peak and mean velocity. Providing the mass of the athlete and/or external load moved are known, acceleration, force, and power outputs can be calculated through the process of differentiation. The addition of a biaxial accelerometer enables the GPT to measure any anterior/posterior deviation present within a movement, facilitating the calculation of angle of lift. This removes the most common limitation associated with the use of LPTs, as all measurements are made with respect to gravity as opposed to the orientation of the unit (Cormie, Deane, & McBride, 2007a; Hori et al., 2007).

#### **3.4.1 Sampling and lifting parameters**

The GPT uses a variable rate sampling method, with level crossing detection to capture and record information. Data points are recorded only when the tether displacement alters by 300  $\mu\text{m}$ , at which point the position is time-stamped with a resolution of 35  $\mu\text{s}$ . This means the data will not be uniformly spaced in time, but instead directly referenced to the displacement of the tether. The raw data is then down sampled to a maximum rate of 50 samples per second (50 Hz), removing noise and thus the requirement to filter when differentiating the data.

The aforementioned information facilitates a variety of lifting parameters to be calculated simultaneously during any one movement. All data is stored through an online cloud system (GymAware Pro; Kinetic Performance Technology, Canberra, Australia), enabling safe extraction of all data variables at any point. For all lifting parameters the GPT calculates outputs based on the displacement (m) data recorded during the concentric phase of the movement. Once displacement has been recorded, differentiation is used to calculate velocity ( $\text{m}\cdot\text{s}^{-1}$ ), which is

differentiated again to obtain acceleration ( $\text{m}\cdot\text{s}^{-1}$ ). Once mass (kg) is a known entity, multiplication with acceleration data enables force (N) outputs to be calculated, with this multiplied by velocity to obtain power (W). For all parameters, peak and mean values can be extracted, with these being both absolute and relative, with peak referring to the maximum value throughout the movement phase, and the average value being taken for the mean (Table 10).

**Table 10.** Equations used by the GymAware PowerTool to calculate displacement and subsequent derivatives.

Variable	GymAware PowerTool
Displacement (m)	$d = \Delta p$
Velocity ( $\text{m}\cdot\text{s}^{-1}$ )	$v_i = (d_{i+1} - d_i)/\Delta t$
Acceleration ( $\text{m}\cdot\text{s}^{-2}$ )	$a_i = (v_{i+1} - v_i)/\Delta t$
Force (N)	$F = ma$
Power (W)	$P = Fv_i$

\*  $d$  = displacement,  $p$  = position,  $v$  = velocity,  $t$  = time,  $a$  = acceleration,  $F$  = force,  $m$  = mass,  $P$  = power

### 3.4.2 Feedback

For both study two and three, feedback was provided to the participants during completion of the monitored movements within the training interventions. For both studies, the VBT groups received auditory confirmation, in the form of an instantaneous “beep” from the GPT, that they had completed a repetition within the target velocity range. If they fell outside of the target range, and different auditory signal was used so they participant was aware they had “missed” a repetition. Within study two only, the comparison group received verbal encouragement throughout the same movements as velocity was not recorded. Previous literature has demonstrated that while feedback conditions promote a higher level of effort than

non-feedback conditions within resistance training, the method by which this feedback is given does not result in worthwhile differences (Weakley et al., 2018; Weakley et al., 2017).

### **3.5 Warm-up**

Prior to all testing and training for each study, participants were supervised during a standardised warm-up. This consisted of five minutes of stationary cycling (Wattbike; Nottingham, UK; 60 rpm, 60 W), followed by an additional five minutes of self-prescribed dynamic stretching and mobility work. Participants were instructed to repeat the same mobility work upon each visit. For study one, participants worked through a series of self-selected loads, gradually increasing to their working set for assessment. For study two and three, participants were required to self-select incremental loads working up to 10% below that of their first working set. MCV of this final warm-up set would be monitored and used to infer the load of their first working set if within a velocity-based intervention group.

### **3.6 Strength and power assessments**

Throughout this thesis, a selection of physical assessments were used to assess the maximal strength and power-producing ability of participants, both pre- and post-intervention. Listed below are the assessments, equipment, and protocols used repeatedly throughout the forthcoming chapters.

#### **3.6.1 Jump assessments**

The use of jumping protocols to assess athletic power-producing ability is prevalent within the literature. Countermovement, static squat, and standing broad jump have all being associated directly with acceleration, sprint ability, and maximal strength in

a range of populations (Cormie, McGuigan, & Newton, 2010; Hermassi et al., 2018b; Otto III, Coburn, Brown, & Spiering, 2012; Rodríguez-Rosell, Torres-Torrelo, Franco-Márquez, González-Suárez, & González-Badillo, 2017). Within this thesis, vertical jumping ability was assessed throughout all studies, with standing broad jump assessed for study three only. For all jumping protocols, participants squat depth was measured prior to jumping through use of a manual goniometer (knee angle  $\sim 90^\circ$ ) to ensure full depth could be attained while maintaining full foot contact. For all protocols, a total of three trials were completed, interspaced with two minutes rest. Jumps were recorded in centimetres to one decimal place. For all studies the mean value of each trial was recorded and used for subsequent data analysis.

#### *3.6.1.1 Countermovement and static squat jump*

The countermovement jump (CMJ) test begun from an erect standing position with hands placed on the iliac crest. At a self-selected pace, participants would squat to their perceived optimum depth, before immediately driving upwards with the aim of attaining maximum vertical height. Participants were instructed to keep legs straight throughout the airborne phase, and their hands in contact with their iliac crest (unless otherwise stated) throughout the jump, with any deviation from this resulting in a void trial.

For the static squat jump (SSJ), participants began in the same position as for the CMJ. When ready, participants would squat to achieve a  $90^\circ$  angle at the knees (verified by a goniometer), while maintaining full foot to floor contact. This position was held for three seconds before participants were instructed to explosively rise upwards into a vertical jump, aiming for maximum height. It was required that no downward motion was recorded prior to jumping following the pause. Participants

were instructed to keep legs straight throughout the airborne phase, and their hands in contact with their iliac crest (unless otherwise stated) throughout the jump, with any deviation from this resulting in a void trial.

#### *3.6.1.1.1 Force plate*

In study one and study three, both CMJ and SSJ protocols were assessed using a floor set, piezoelectric force plate (Kistler, Winterthur, Switzerland). Prior to any testing, the force plate was 'zeroed', with this process repeated prior to every trial throughout data collection. Ground reaction force (GRF) data during each jump were sampled at 1500 Hz and recorded by an IBM compatible computer, running Windows 7. Real-time force data were logged via Cortex software (Motion Analysis Corporation, CA, USA) before being transferred to MatLab R2016b (MathWorks, MA, USA) for processing. Custom code was written enabling vertical jump height to be calculated through application of the impulse-momentum relationship. Acceleration was derived from the vertical GRF, adjusting for the gravitational constant ( $9.81 \text{ m}\cdot\text{s}^{-2}$ ). Integration could then be applied to the acceleration data, deriving velocity of the centre of mass (COM) at take-off. This enabled jump height to be calculated following use of a uniform acceleration equation (Moir, 2008).

Prior to jumping, the participants COM was recorded during approximately three seconds of stationary standing on the force plate. This data were averaged and defined as 'zero COM displacement'. Once this point had been established, take-off was defined as the point at which recorded force decreased below zero (N) by two standard deviations of the zero displacement average for a minimum of ten frames, at which point the first frame was marked and considered true take-off (McErlain-Naylor, King, & Pain, 2014; Richter, O'Connor, Marshall, & Moran, 2014).

#### *3.6.1.1.2 Just Jump contact mat*

For study two, CMJ was assessed via use of a Just Jump contact mat (Probiotics; AL, USA), with the participant holding a 0.4 kg dowel behind their head (back squat position; Cormie et al., 2010). The dowel was required to remain in contact with the participants' upper back throughout the full trial. Participants were instructed to position themselves in the centre of the contact mat prior to each jump, and ensure they landed as close to the centre as possible. For this method, particular emphasis was placed on the participant maintaining straight legs throughout the airborne phase, as bending or "tucking" at the knee can significantly affect the captured data.

Research has previously demonstrated high levels of intrasession reliability for the Just Jump system in males, through high intraclass correlations ( $> 0.92$ ), low standard error of the measurement (2.3%), and low coefficient of variation (4.2%) following six repeated trials over two collection days (Nuzzo, Anning, & Scharfenberg 2011). The authors of this study further suggest that as training experience increases, so too will the associated reliability of the device.

#### *3.6.1.1.3 GymAware PowerTool*

The GPT was used to assess vertical jumping performance in study one, with data compared to that obtained via the force plate method. For both CMJ and SSJ, participants were required to wear a Velcro belt directly in-line with the naval, enabling the connection of the tether from the GPT. The device was magnetically secured to the floor between the participant's feet. Once in position, the GPT was 'zeroed' with the participant on their toes, enabling calculation of any vertical movement past this point. It was essential that the GPT was placed exactly central

with the accelerometer facing forwards, ensuring any frontal deviation was factored into the calculations during both protocols.

#### *3.6.1.2 Standing broad jump*

For the standing broad jump (SBJ), participants began in the same position as for the CMJ. At a self-selected pace, participants would squat to their perceived optimum depth, before immediately driving both forwards and upwards, with the aim of attaining maximum forward distance. Participants were instructed to land with their feet parallel, and to keep their hands in contact with their iliac crest throughout the jump, with any deviation from this resulting in a void trial.

##### *3.6.1.2.1 Force plate*

The SBJ protocol was assessed via force plate analysis. The participant set up as previously described for the CMJ and SSJ. Following identification of the point of true take-off (height of COM at take-off), both vertical and horizontal COM take-off velocities were calculated by integrating the respective force traces. Time of flight from take off until the COM vertical displacement equalled zero was calculated using vertical velocity through use of uniform acceleration equations. This was done to remove the effect of landing technique on jump distance. Flight time was subsequently used to calculate horizontal displacement of the COM during flight and recorded as SBJ distance.

#### **3.6.2 One repetition maximum**

For all studies within this thesis, participants' 1-RM was measured. For all attempted maximal repetitions, strong verbal encouragement was provided to motivate subjects to give maximal effort throughout. Spotters were available for all attempts,

however if any contact was made with the bar or participant, the trial was void and had to be reattempted. Within study one, 1-RM acted as a descriptive measure enabling correct loading during subsequent trials. For studies two and three, 1-RM was used to assess maximal isoinertial strength both pre and post the associated periodised resistance training intervention. All 1-RM assessments were completed within a custom-built power cage (Watson; Somerset, UK), with 0.5 – 25 kg calibrated weight plates, and a 20 kg calibrated barbell (Eleiko; Sweden).

During study one and part of study two (back squat and bench press), participants completed 1-RM assessment in accordance with guidelines established by the National Strength and Conditioning Association (Haff & Triplett, 2015). Participants completed an initial set of 8-10 repetitions with the empty bar; followed by 5-6 repetitions at ~50% estimated 1-RM. This was increased to ~70% estimated 1-RM for 3-5 repetitions, and finally ~90% estimated 1-RM for a single repetition. At this stage the researcher dictated incremental load increases, until 1-RM was achieved maintaining correct technique, through a full range of motion. Achievable load increases were selected, with the aim of attaining a true repetition maximum within three to five attempts. If an attempt was failed, the load was decreased until a single repetition was completed. Each series of repetitions throughout the full protocol was interspaced with 3-5 min rest.

For the remaining lifts within study two (strict overhead press and deadlift), and all lifts assessed during study three, 1-RM was established following procedures similar to those described by Sánchez-Medina et al., (2013; 2017). Initial load was set at ~30% estimated 1-RM, or 20 kg (empty bar), with incremental increases of ~5% estimated 1-RM following completion of successful repetitions. For light loads



( $\leq 50\%$  estimated 1-RM) participants completed three repetitions, decreasing to two repetitions for medium loads (55-80% estimated 1-RM), and a single repetition for high loads ( $\geq 85\%$  estimated 1-RM). If participants continued to successfully complete repetitions after achieving their estimated 1-RM, incremental load increases were applied until a true 1-RM was achieved.

#### *3.6.2.1 Velocity profiling*

During all 1-RM assessments the GPT was attached to the weightlifting bar enabling real-time collection of time-displacement data, and associated derivatives previously described. For the back squat, bench press, and strict overhead press, the GPT tether was attached 10 cm from the end of the weightlifting bar, with this being centred for the deadlift (Figure 6). During each incremental load, MCV was recorded. For loads with more than a single repetition, the mean data point was used. Following completion of the 1-RM assessments, MCV was plotted in relation to relative percentage of 1-RM for each participant, enabling an LVP to be created. A second-order polynomial was fitted, with the SD associated with this line (SEE) used to create CIs acting as upper and lower 'zones' of acceptable velocity at a given relative percentage (Figure 7).

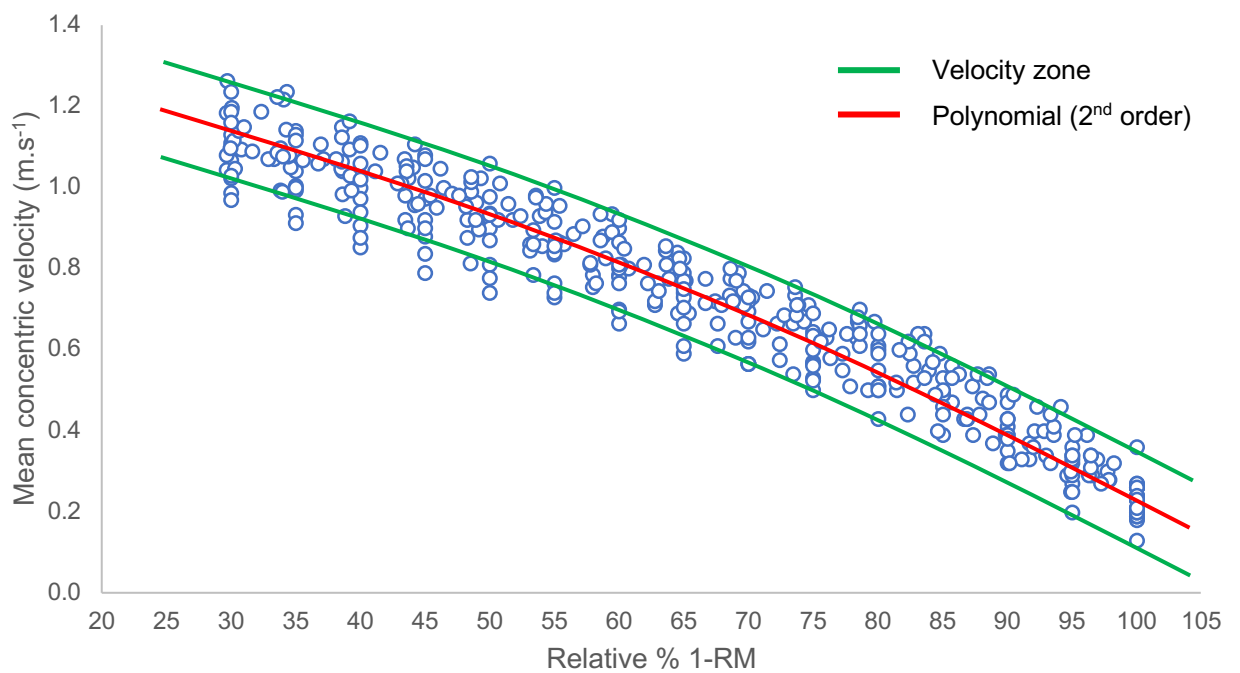
a)



b)



**Figure 6.** Attachment site of GymAware PowerTool for the back squat, bench press, and strict overhead press (a), and the deadlift (b)



**Figure 7.** Example load-velocity plot for a back squat complete with associated lines

### **3.6.3 Multi-joint movements**

A range of free-weight, multi-joint, compound movements were assessed during the experimental studies, these are described below. For all repetitions, participants were instructed to maintain eccentric control, before generating maximal force during the concentric phase. For all movements, participants were allowed to use specialised supportive equipment in the form of lifting shoes, knee sleeves, and / or a lifting belt. Chalk was also provided to all participants if they wished to use it. In order for such equipment to be used, participants were required to use it consistently during all testing / training trials. No additional equipment that has been shown to aid lift propulsion, such as knee or elbow wraps, were permitted.

#### *3.6.3.1 Back squat*

The back squat was initiated with the bar resting across the upper back of the participant with feet flat on the floor, at shoulder width or slightly wider (based on preference). At a self-selected pace, the participant would simultaneously flex at the ankle, knee and hip; maintaining tension in the back with chest up and chin forward. Once the knee angle was at 90° in relation to the hip, the participant was instructed to drive upwards, pushing through the floor, maintaining tension in the back as the knees and hips extended in unison. Full unassisted extension of the knee and hip were required for the lift to be counted.

#### *3.6.3.2 Bench press*

For the bench press, the participant adopted a prone position on the weightlifting bench. At all times throughout the movement the participant was instructed to keep their head, shoulders, and hips in contact with the bench, with both feet flat on the floor. Participants were instructed to place hands in a neutral position, roughly

shoulder width apart (based on preference), with this remaining consistent throughout subsequent trials. At a self-selected pace, the barbell would be unracked (with assistance from the supervising researcher), before controlled eccentric lowering to chest level; at which point the participant pressed the barbell to the start position. Participants were instructed to avoid both pausing at the chest, and bouncing off the chest, with the latter resulting in a failed lift. Full unassisted extension at the elbow was required for the lift to be counted.

#### *3.6.3.3 Strict overhead press*

For the strict overhead press, the participant was stood fully erect, with the bar racked in-line with the clavicle. When ready, the participant would grasp the bar, outside the shoulders, with an overhand grip, and un-rack the bar. Maintaining a soft-lock through the legs, the participant would drive the bar upwards, bringing the head under the bar as soon as possible. If at any stage the participants knees flexed, or ankles extended, the repetition was void. Full unassisted extension at the elbow was required for the lift to be counted. Participants were instructed to control the lowering the of the bar to the clavicle, before re-racking.

#### *3.6.3.4 Deadlift*

The deadlift was initiated with the participant standing fully erect, with the bar at their ankles. When ready, the participant would flex at the hip, knee and ankle, maintaining a straight back, with their chest and chin up; grasping the bar inside shoulder width. Participants could adopt an overhand or alternate grip. At this point the participant would drive up by pushing through the floor, maintaining tension in their back; hip, knees, and ankles extending in unison. Arms would remain fully extended throughout the full repetition range. Once fully erect, the shoulder blades

would be drawn back, and hips drawn forward to complete the repetition. Participants were instructed to control the lowering of the bar to the floor.

### **3.7 Resistance training interventions**

A similar strength training design was employed for studies two and three. The intensity, and volume of these programmes were devised based on methods previously described (Baker 1995; 2007; 2013), following a wave-like periodisation structure. Briefly, weeks one to three were completed with a progressively increasing intensity, and simultaneous decreasing volume. Week four reverted back to a base volume, similar to that of week two, acting as a within programme maintenance phase. At week five, the total volume is similar to that of week three, with more emphasis on intensity and peaking. Week six was used as a peak intensification stage and simultaneous de-load, focusing on the highest intensity and neural stimulus, with the lowest total volume (Baker 1995; 2007; 2013; Table 11). For both studies, interventions consisted of six continuous weeks of training, with two sessions completed each week. Prior to each study, participants were required to complete a minimum of one 1-RM (specifics detailed within each study chapter), enabling individualised programmes to be created, and further allowing velocity profiles to be recorded and integrated within the intervention.

**Table 11.** Descriptive characteristics of both training sessions within weeks 1-6, completed by all training intervention groups for the compound movements being assessed (study two: back squat, bench press, strict overhead press, and deadlift; study three: back squat).

Session 1											
Week 1		Week 2		Week 3		Week 4		Week 5		Week 6	
Reps	% 1-RM	Reps	% 1-RM	Reps	% 1-RM	Reps	% 1-RM	Reps	% 1-RM	Reps	% 1-RM
8	70	8	70	6	75	8	70	6	77.5	5	85
8	70	6	75	5	80	6	75	5	85	3	90
8	70	5	80	3	85	5	80	3	90	2+	95
Session 2											
Week 1		Week 2		Week 3		Week 4		Week 5		Week 6	
Reps	% 1-RM	Reps	% 1-RM	Reps	% 1-RM	Reps	% 1-RM	Reps	% 1-RM	Reps	% 1-RM
8	70	8	70	6	75	8	70	6	77.5	4	70
8	70	6	75	5	82.5	6	75	4	87.5	4	70
8	70	5	82.5	3+	87.5	5	82.5	2	92.5	4	70

\* “+” denotes an opened ended set, whereby participants would complete repetitions until they felt they would not achieve the next with acceptable technique

In addition to the assessed compound movements (study two: back squat, bench press, strict overhead press, and deadlift; study three: back squat), supplementary exercises were included within the training intervention. To ensure consistency across interventions, sets and repetitions were equated, with load dictated via specific equations, using body mass, or through use of a RIR approach (Table 12; Helms et al., 2016). Participants were instructed to self-select a load they perceived could be completed for eight repetitions, without faulting technique, while only completing six. The previous load was used to inform the subsequent set; however, participants could alter resistance on a set-by-set basis by a minimum of 2.5 kg.

**Table 12.** Methods used to calculate load of additional exercises completed during both experimental interventions

Exercise	Load calculation	Study	Additional
Seated row	2 RIR	2	
Barbell hip thrust	+ BM	2	
CMJs	BM	2	With 0.4 kg dowel
Plyometric push-ups	BM	2	
Walking lunge	(6-RM walking lunge) $\times$ 0.6	2 & 3	
Romanian deadlift	(1-RM back squat) $\times$ 0.5	3	
Step ups	(1-RM back squat) $\times$ 0.4	3	Knee at 90°
Nordic curls	BM	3	
Box jumps	BM	3	Box at mid-thigh

\* BM: body mass; RIR repetitions in reserve; RM: repetition maximum; + BM: completed with body mass on the barbell

\*\* 6-RM walking lunge calculated (Ebben et al., 2008): *6-RM squat (kg; 0.52) + 14.82 kg*

For both training groups, across both experimental studies, relative training loads (% 1-RM), number of sets and repetitions, and inter-set rest time (3 min) were equal

throughout the six-week intervention. Training programmes were initially designed with equated total volume (sets x repetitions x relative load), however, as the VBT groups load and repetitions were dictated via real-time MCV monitoring, deviations from this equated volume occurred. This variance of total lifting volume was allowed to occur, as it was deemed a true representation of VBT, and how MCV can impact other training variables.

Regardless of training intervention, participants were instructed to maintain eccentric control, before generating maximal force throughout the concentric phase of all compound lifts. All training was completed under the direct supervision of the lead investigator, at the same time of the day ( $\pm 1$  hour) for each subject, and under constant environmental conditions ( $\sim 20$  °C). In preparation for each session, participants were guided through a warm-up as described in section 3.5. Strong verbal encouragement was provided to all participants to motivate them to give maximal effort throughout the sessions.

### **3.7.1 Velocity-based training**

In order to successfully integrate velocity monitoring into the base resistance training programme for the VBT groups, a combination of velocity zones and velocity stops were employed. For the key movements within each experimental intervention (study two: back squat, bench press, strict overhead press, and deadlift; study three: back squat), MCV monitoring was utilised to dictate changes in load lifted, and the number of repetitions completed, in a real-time set-by-set basis. As previously discussed (section 2.3.4.2), velocity zones act as an acceptable bandwidth in relation to the target velocity, factoring in the error associated around the performance variable. In comparison, velocity stops represent a lower velocity



threshold, beyond which repetitions within a set will stop in an aim to limit neuromuscular fatigue. While evidence is available on both as a means of monitoring MCV individually, within the proceeding data collections they were combined.

During each repetition, participants were provided with real-time auditory feedback based on the MCV of each repetition in relation to the predetermined zone (as discussed in section 3.4.2). Based on the protocol by which the LVPs were established (section 3.6.2), the MCV of the completed repetitions (relative load < 80% 1-RM: two repetitions; relative load > 80% 1-RM: one repetition) was then reviewed in comparison to the relative velocity zone data, enabling objective modification of subsequent loads if deemed necessary. This meant that load increments / decrements were not standardised throughout data collections, but instead specific to the athlete's current performance in comparison to the LVP previously established.

#### *3.7.1.1 Velocity zones*

For study two, group zones for each movement were created utilising a combination of previously published data (González-Badillo & Sánchez-Medina, 2010; Pallarés et al., 2014; Sánchez-Medina et al., 2013; Sánchez-Medina et al., 2017), and data collected within the pre-testing velocity profiling of the respective study. From this consolidation of data, specific group velocity zones were calculated for each movement, for each relative load (i.e. 70% 1-RM, back squat: 0.74 – 0.88 m·s<sup>-1</sup>; bench press: 0.58 – 0.69 m·s<sup>-1</sup>; strict overhead press: 0.77 – 0.91 m·s<sup>-1</sup>; deadlift: 0.51 – 0.65 m·s<sup>-1</sup>). The group zones were created by consolidating all load-velocity

data and calculating associated standard error. This enabled confidence intervals to be produced, acting as an upper and lower boundary of acceptance.

Within study three, one intervention group completed training as prescribed within study two, with velocity zones created via group data. In comparison, the other groups load and repetitions were dictated via individual velocity zones, specific to their pre-training 1-RM assessments. While relative load and total training volume was equated between groups, the concentric velocity target for each individual differed based on their own velocity profile and the associated standard error.

As previously discussed (section 2.3.4.2), while 95% CIs have become common practice within load-velocity profiling, the resultant velocity zone created detracts from the sensitivity of this variable by encompassing too large a spread of data (Table 9). For this reason, within both study two and three, CIs utilised as velocity zones were calculated from one SD (~68%), creating smaller, more specific boundaries. Furthermore, in order to increase the specificity of the velocity zones, the associated standard error was calculated from only the data within the intended programmed intensities (i.e. 70-95% 1-RM). This removed the additional data collected (30-65% and 100% 1-RM) and the accompanying larger spread, thus lowering the created velocity zones. In both studies, the data were visually inspected to ensure as close to all intensities (70-95% 1-RM) were encompassed within the upper and lower velocity zone employed.

#### *3.7.1.2 Velocity stops*

For all velocity-based interventions, velocity stops were integrated into each set at 20% below the mean target velocity of each specific zone, ensuring participants

remained within the targeted velocity range during the set. If a repetition fell outside of the minimum threshold of the zone, but was within the 20% drop-off, participants received a specific auditory cue and were instructed to complete a final repetition. If the second repetition was outside of the prescribed zone the set was stopped. If a repetition fell outside of the 20% drop-off, repetitions were stopped instantly, and the set finished. Previous literature has explored the use of such cut-offs, with 20% being considered optimal in comparison to greater zones (i.e. 40%) (section 2.3.4.1).

### **3.8 Statistical analysis**

Due to the differing statistical approaches adopted across each experimental study design, statistical methods are described in each independent chapter. All descriptive statistics are presented as mean  $\pm$  SD unless otherwise stated.

## **4.0 Validity and reliability of a linear positional transducer across commonly practiced resistance training exercises**

## **4.1 Preface**

This PhD thesis features a series of intervention studies involving the manipulation of training variables within a periodised resistance training programme. The completion of pre- and post-intervention physical assessments enabled the outcomes of each programme to be evaluated and cross-examined. Thus, determining the validity and reliability of the tools and assessments used is fundamental to confidently evaluate the differences in performance. This allows conclusion to be drawn as to whether the reported changes are attributed to random error or the training intervention being investigated.

While commonly practiced, and well referenced methods of assessment are being utilised throughout this thesis (Markovic, Dizdar, Jukic, & Cardinale, 2004; Seo et al., 2012), the novel method of dictating load based on real-time collected MCV is at the centre of the subsequent studies. As such, prior to such methods being integrated into resistance training programming, it is essential that the tools proposed to be utilised in such collections are first validated against criterion methods. Further to this, once established as providing valid measures, the error associated between visits must be established.

## 4.2 Introduction

Resistance exercise is widely recognised as an essential stimulus for the development of muscular strength and power, and thus deemed fundamental to many athletic periodised training regimes (Harries, Lubans, & Callister, 2012, 2015a). One approach to ensure the effectiveness of such regimes is through the monitoring and manipulated use of the acute training variables (Kraemer, 1983a, 1983b). Traditionally, variables were generally limited to the volume, intensity, and rest allocated to a given exercise, as well as the order in relation to other movements (Kraemer, 1983a, 1983b). However, as technology and training practises have developed, access to devices which monitor more intricate variables such as lift velocity have become commercially available (Kraemer & Ratamess 2004; Sánchez-Medina & Gonzalez-Badillo, 2011a; Sánchez-Medina et al., 2017). The use of velocity as a variable has been shown to offer insight into the development of an athlete's force-velocity profile and current state of fatigue, as well as assist in the design and monitoring of longitudinal training regimes (Pareja-Blanco et al., 2017; Pereira & Gomes, 2003; Sánchez-Medina & González-Badillo, 2011a).

The velocity at which a given lift is performed is directly related to the force-velocity relationship of the athlete, the relative intensity applied, the movement pattern and associated biomechanics, and the athlete's current state of fatigue (Haff, 2012; Sánchez-Medina & Gonzalez-Badillo, 2011a; Sánchez-Medina et al., 2017). This fatigue is postulated to be dependent on the extent and magnitude of preceding training and as such, the ability of coaches and practitioners to quantify such measures and adapt subsequent training is of great interest (Chiu & Barnes, 2003).

Achievable concentric lift velocity has been shown to be directly related to fatigue, demonstrated through a decline in MCV over continuous repetitions (González-Badillo & Sánchez-Medina, 2010; Sánchez-Medina & González-Badillo, 2011a). As such, it has been suggested that real-time velocity allows an indirect insight into the athlete's current physiological status and readiness to train (Gonzalez-Badillo et al., 2015). This allows informed decisions to be made on factors such as; proposed training volume, prescribed training loads, and regime progression (Kraemer & Ratamess, 2004). This is often done through utilisation of athlete velocity profiling, facilitating the prediction of one repetition maximum, and the prescription of individualised velocity training zones (Banyard et al., 2018; Jovanović & Flanagan, 2014; Kraemer & Ratamess, 2004). Due to the potential implication of these measures, the accurate and reliable assessment of these performance variables is essential.

Traditionally, the direct acquisition of such variables required the use of a force plate and/or high-speed video analysis, limiting research to specialised facilities due to labour- and resource-intensive protocols (Lamas et al., 2012). Whilst these methods are widely considered “gold standard” in terms of performance assessments, the transferability to an applied setting has been questioned (Cronin et al., 2004; Cronin et al., 2002). To overcome this, kinematic systems, including LPTs, are becoming increasingly popular tools for quantifying the force, power, and velocity outputs of resistance training exercises (Argus et al., 2012; González-Badillo et al., 2015). Whilst such monitoring tools are becoming prevalent within the literature, and more so the applied environment, the validity and reliability of specific devices has yet to be fully examined within the literature.

The GPT is a commercially available LPT. It has been utilised within an array of research studies evaluating velocity, acceleration, force, and power, across a range of resistance training movements (Argus et al., 2012; Argus et al., 2011a; Beaven et al., 2012; Crewther et al., 2011a). However, minimal research exists exploring the validity and intra-visit reliability of the device, especially with reference to criterion measures. Drinkwater et al. (2007a) evaluated the validity of the GPT, during free-weight bench press, and Smith-machine back squat and bench throw. Eccentric and concentric peak and mean power output were calculated through use of the GPT and validated against two-dimensional video data. Validity was quantified through use of standard error of measurement, and coefficient of variation (3.6-14.4 W, 1.0-3.0%, respectively). The relationships between the criterion device (video) and the GPT were evaluated using Pearson's product moment, producing strong correlations ( $r \geq 0.97$ ). Whilst the data presented suggests high levels of validity, the use of manually digitised two-dimensional video analysis, which has an increased risk of both systematic and random error, limits the practical applications of this research.

Further research (Crewther et al., 2011b) investigated the validity of the GPT during weighted squat jumps (20 kg, 40 kg, 60 kg, and 80 kg). Concentric peak force and power of twelve trained participants were assessed via comparisons of the GPT and a force platform (Kistler, Winterthur, Switzerland). Relative validity was quantified using least squares regression ( $r = 0.59-0.87$ ), with Bland-Altman plots revealing high random error across all assessed resistances for peak force (20 kg:  $\pm 579$  N; 40 kg:  $\pm 255$  N; 60 kg:  $\pm 255$  N; 80 kg:  $\pm 414$  N), and peak power (20 kg:  $\pm 879$  W; 40 kg:  $\pm 611$  W; 60 kg:  $\pm 748$  W; 80 kg:  $\pm 762$  W). The authors suggested that the error was likely due to the differing methods between measuring devices. Force



plates measure the centre of mass directly, while the GPT differentiates this variable from collected time-displacement data. Thus, any body movement occurring independently of the bar, potentially affecting centre of mass, will be missed by the GPT (Crewther et al., 2011b). This has the potential to skew results as discrepancies will be present between the recorded data.

#### **4.2.1 Research aims**

The limitations of the above research highlight a clear need for further investigation into the validity of the GPT, specifically with reference to criterion devices. Furthermore, to the author's knowledge, the intra-visit reliability of the GPT, set within a resistance-based exercise paradigm, has yet to be examined. Additionally, no research has explored the only true measured variable from the GPT. As all data is derived from displacement, research should first ascertain the error associated with this key variable. Producing outcome measures that address these issues would allow researchers and practitioners to make informed decisions about use of the GPT within athletic programme design and monitoring. Researchers should endeavour to ensure data collected is applicable to common strength and conditioning practices. This should be achieved by assessing the validity and reliability of the GPT on commonly employed lifts, which have a range of techniques, lift distances, and velocities.

Therefore, the aims of this research were to firstly investigate and establish the validity of the GPT against integrated criterion devices. Further to this the assessment of associated reliability (athlete and LPT) of the GPT was reviewed over three repeated trials. These aims were addressed by evaluating displacement, peak

and mean velocity, and peak and mean force outputs of the back squat, bench press, deadlift (free-weight), and CMJ within a trained population group.

### **4.3 Research design**

The following section builds upon the already outlined general methods within section 3.0, specifically outlining the approaches of this research chapter.

#### **4.3.1 Experimental approach**

A repeated measures design was employed to determine the validity and reliability of the GPT. Concentric movement phase was measured via simultaneous collection of performance variables, including lift displacement, peak and mean velocity, and peak and mean force. Vertical jump performance was measured via simultaneous collection of jump height and force output. The determination of the GPT validity was established by comparison to a three-dimensional motion capture system, and piezoelectric integrated force plate. Relationships between measuring devices were quantified using least products regression and expressed as an  $R^2$  value. One-way analyses of variance (ANOVA) with three repeated trials were conducted to examine between trial differences of all GPT calculated variables, with typical error (TE; expressed as a percentage; 90% coefficient of variation; CV) and smallest worthwhile change (SWC) calculated to quantify between trial variance.

#### **4.3.2 Participants**

Thirteen resistance trained participants (male: 9; female: 4; mean  $\pm$  SD, age: 26.5  $\pm$  4.8 years, stature: 174.1  $\pm$  9.5 cm, body mass: 81.9  $\pm$  12.1 kg), volunteered to take part in the study. All subjects were free from injury, had at least two years of resistance training experience and had been training for a minimum of six months

prior to the start date. All participants had experience of the movements required prior to acceptance on the study. Written informed consent was provided, which was approved by a local ethics committee in line with the Helsinki Declarations for research with human volunteers.

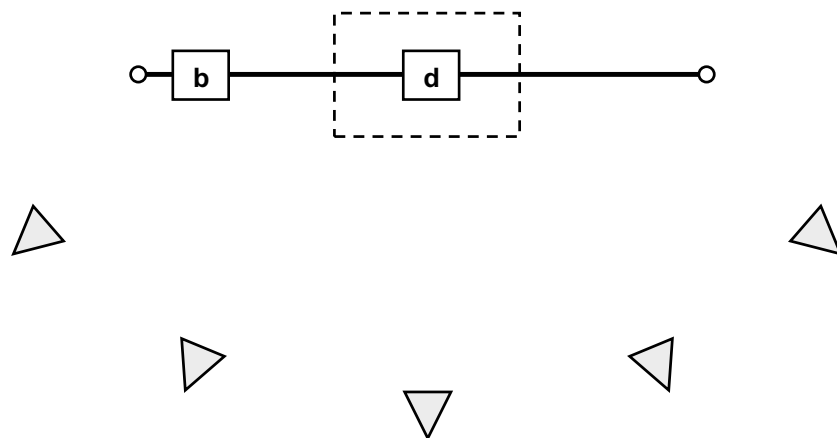
#### **4.3.3 Procedures**

Following recruitment, all participants completed a 1-RM test protocol for back squat, bench press, and deadlift. A successful lift was classified as outlined previously (section 3.6.3). For each individual exercise, participants followed a standardised warm up (section 3.5), before completing a 1-RM as outlined within section 3.6.2.

Participants completed three further visits, interspaced with a minimum of 96 hours rest (maximum 120 hours). Upon each visit, participants completed a standardised warm-up prior to any physical activity (section 3.5). Following the warm-up, subjects completed the testing protocol, consisting of three repetitions of free-weight back squat, bench press and deadlift (all completed at 80% 1RM), followed by a set of three CMJs. For all lifts, participants were instructed to maintain eccentric control, before generating maximal force during the concentric phase of each repetition. For the CMJ, subjects were instructed to keep their hands in contact with their hips (iliac crest) throughout the movement.

For each trial completed, the GPT was attached to the powerlifting bar (back squat, bench press, and deadlift) or athlete (CMJ), with the subject standing on a force plate (Kistler; Winterthur, Switzerland). For the back squat and bench press, the GPT tether attachment site (GA) was located 10 cm from the end of the bar, with

this being centred during the deadlift (Figure 8). For the CMJ, the GPT tether was attached directly to the athlete's midriff (in line with the naval) via a Velcro fastening. Time-displacement data were measured and recorded by the GPT. When tether displacement was detected ( $\geq 300 \mu\text{m}$ ), it was time-stamped ( $35 \mu\text{s}$ ), and automatically down-sampled to 50 points per second (50 Hz). Bar kinematics were recorded using a five-camera three-dimensional motion capture system (Rapture-E; Motion Analysis Corporation, CA, USA; 150 Hz). Three passive retro-reflective markers (12 mm diameter) were used, two placed on the powerlifting bar (diametric ends; Figure 8) and one on the GA. Force data were collected (1500 Hz) during all movement trials except bench press.



**Figure 8.** Data capture set-up, detailing force plate (- - -), powerlifting bar (—), cameras ( $\nabla$ ), markers (o), and GymAware attachment site (back squat and bench press: b; deadlift: d).

#### 4.3.4 Data processing

Marker positions were identified using Cortex (v5.3.1, Motion Analysis Corporation, Santa Rosa, CA, USA) and analysed using custom written MATLAB code (R2016a, MathWorks, Natick, MA, USA). Marker data were smoothed using a zero lag 2nd order Butterworth low-pass filter, with a cut-off frequency of 6 Hz. For each trial a

virtual midpoint (VM) was created by taking the mean position of the diametric markers, representing the true centre of the bar. The VM and GA position data from the motion capture system were used to represent bar, and GymAware tether movement, respectively. Simultaneous collection of data were completed by the GPT, and analysed via the built-in GymAware Pro (GAP) software (Kinetic Performance Technology, Canberra, Australia).

For all movements, the concentric phase of each trial was analysed from the onset of movement to a predefined end point. The GAP software automatically detects the start of the concentric phase as the first moment the tether data increases ( $\geq 300 \mu\text{m}$ ) above its lowest vertical position. End points are defined as the point of greatest vertical displacement occurring after the predefined start. To minimise differences due to identification of start and end points, analyses closely matching the GAP software were used within the marker positional analysis. For the back squat and bench press, the start of the concentric phase of the movement was identified as the frame at which the vertical position was at its lowest point. For deadlift, the start of the concentric phase was identified as the first frame the vertical position was greater than  $300 \mu\text{m}$  above the starting position. For all movements, the end point was identified as the point where marker vertical position was at its highest following the identified start point.

Barbell displacement was measured as the vertical distance between the predefined start and end of each trial. The first and second derivatives of displacement data were calculated to provide bar velocity and acceleration, respectively. The differentiation method used by the GAP software takes the difference between two adjacent points, divided by the change in time. Subsequently, force is calculated by

multiplying acceleration by inputted mass. In contrast, the central difference method was used for the differentiation of marker data. This method provides an estimate of the slope of the tangent at a single point using the preceding and succeeding data (Hamill, Knutzen, & Derrick, 2015). This allows the calculation of instantaneous velocity and acceleration at a specific time point, rather than the average between two points (Table 10). Comparative force data was obtained via direct measurement from the force plate. Peak and mean values were extracted for velocity and force enabling comparison between collection methods.

To calculate jump height, the GAP software took the difference between vertical displacement of the tether from a predefined start point (participant standing on toes), to the point of the highest vertical position. For comparison, jump height was calculated according to the impulse-momentum relationship, using change in centre of mass velocity from the captured force plated data (section 3.6.1.1.1).

#### **4.3.5 Statistical Analysis**

For all variables, the within-trial (visit) data for each participant were averaged and the mean result used for statistical analysis. Statistical analyses were conducted using SPSS 22.0 (Chicago, IL, USA) with the alpha level for significance set at  $\alpha = 0.05$ .

Validity between the criterion (motion capture and force plate) and GPT calculated variables were evaluated using least products regression and expressed as an  $R^2$  value. This enabled quantification of validity between measures across all variables, including bar displacement, jump height, peak/mean velocity and peak/mean force. To assess reliability, a within-trial one-way ANOVA test with repeated measures

(1x3) were conducted to examine the between visit differences across all GPT variables. Within-participant variation was reported as TE and displayed as a percentage (90% CI) following completion of a consecutive pairwise analysis spreadsheet (Hopkins, 2015). Furthermore, SWC was calculated by multiplying the mean between-participant standard deviation by 0.2 (representing a small Cohen effect size; Drinkwater, et al., 2005) and presented as both absolute and relative values. G\*Power 3.1.9.4 (Düsseldorf, Germany) was used to calculate post-hoc achieved power, utilising  $\alpha$ , effect size (Cohen's  $d$ ; using  $\eta^2$ ), and sample size (Faul, Erdfelder, Lang, & Buchner, 2007). Additionally, estimated sample-size requirements for subsequent research were calculated using the reported TE and SWC, using methods described by Hopkins (2000). As the GPT derives all performance variables from time-displacement data, the power-analyses were only run on this variable across movements.

## **4.4 Results**

### **4.4.1 Validity**

Correlations between the GPT and the GA and VM sites for all kinematic variables resulted in an  $R^2 \geq 0.99$  for back squat and  $R^2 \geq 0.91$  for bench press (excluding VM displacement;  $R^2 = 0.85$ ). For deadlift, correlations resulted in an  $R^2 \geq 0.92$  for all kinematic variables, barring mean velocity for both GA and VM sites;  $R^2 = 0.54$  and  $R^2 = 0.69$ , respectively (Table 13; Figure 9).

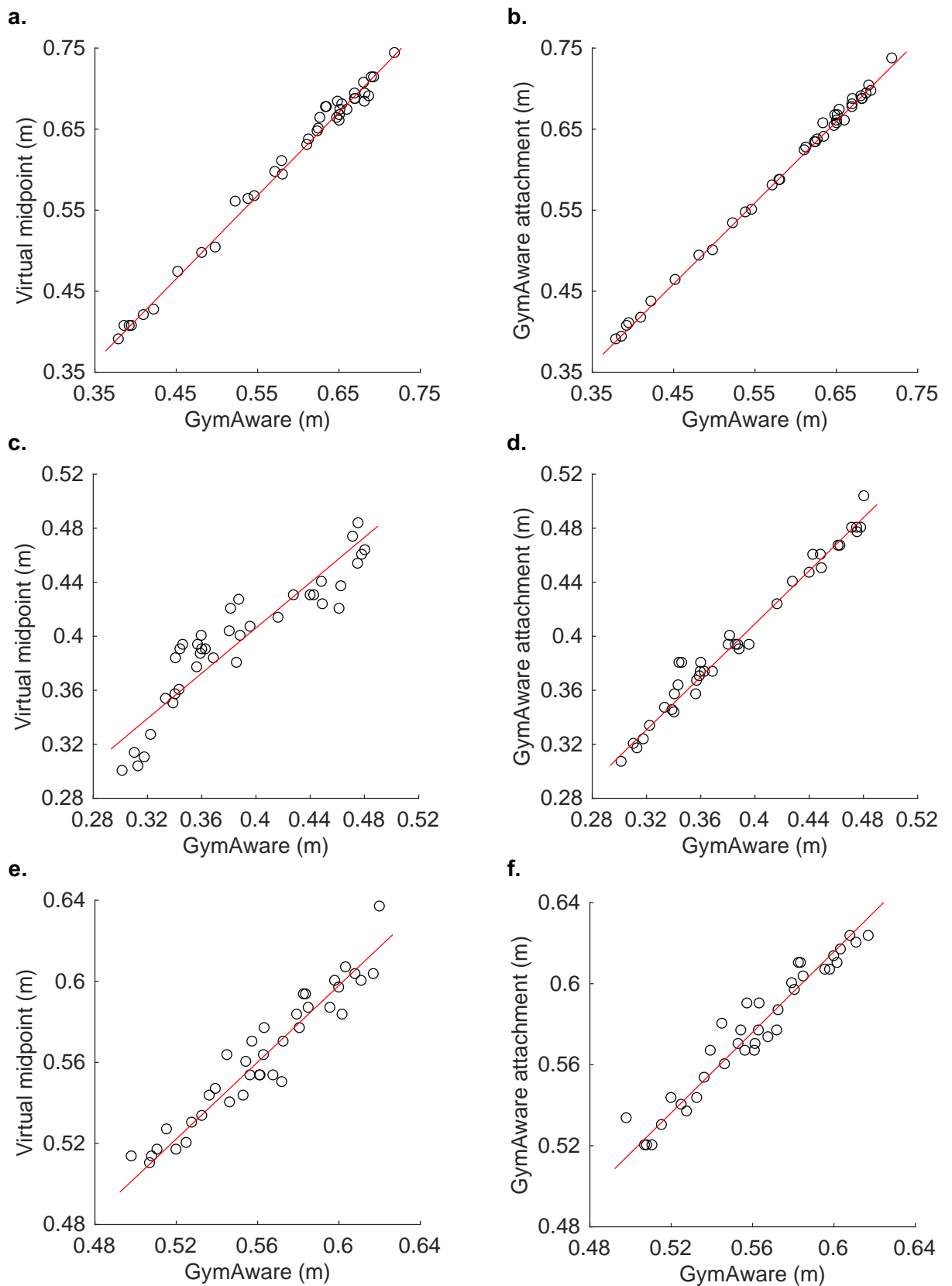
Correlations for back squat kinetics resulted in an  $R^2 \geq 0.99$  for peak and mean force (mean difference  $\pm$  SD: peak force =  $136.4 \pm 86.0$  N; mean force =  $28.0 \pm 39.1$  N). Similarly, strong correlations of  $R^2 = 0.97$  and  $R^2 = 0.94$  for peak and mean force respectively (peak force =  $-14.5 \pm 69.0$  N; mean force =  $52.0 \pm 74.6$  N) were found

for deadlifts. For CMJ, correlations between the GPT and calculated jump height had  $R^2 = 0.88$ .

**Table 13.** Mean difference of kinematic variables between the GymAware power tool and the GymAware attachment (GA) and virtual midpoint (VM) sites [means  $\pm$  SD ( $R^2$ )].

	<b>Displacement (m)</b>	<b>Peak velocity (<math>\text{m}\cdot\text{s}^{-1}</math>)</b>	<b>Mean velocity (<math>\text{m}\cdot\text{s}^{-1}</math>)</b>
<b><i>Back squat</i></b>			
GA	-0.009 $\pm$ 0.005 (0.99)	0.005 $\pm$ 0.007 (0.99)	0.029 $\pm$ 0.010 (0.99)
VM	-0.019 $\pm$ 0.010 (0.99)	-0.022 $\pm$ 0.025 (0.99)	0.014 $\pm$ 0.013 (0.99)
<b><i>Bench press</i></b>			
GA	-0.009 $\pm$ 0.009 (0.98)	0.002 $\pm$ 0.007 (0.99)	0.017 $\pm$ 0.016 (0.93)
VM	0.001 $\pm$ 0.022 (0.85)	0.009 $\pm$ 0.026 (0.91)	0.020 $\pm$ 0.010 (0.97)
<b><i>Deadlift</i></b>			
GA	-0.016 $\pm$ 0.009 (0.94)	0.004 $\pm$ 0.004 (0.99)	0.100 $\pm$ 0.037 (0.54)
VM	0.001 $\pm$ 0.010 (0.92)	-0.014 $\pm$ 0.011 (0.99)	0.031 $\pm$ 0.029 (0.69)





**Figure 9.** Least products regression displacement comparisons from GymAware to virtual midpoint (a, c, e) and GymAware attachment (b, d, f). Back squat (a, b), bench press (c, d) and deadlift (e, f).

#### **4.4.2 Reliability**

For all trial reliability data following a within-trial repeated measures ANOVA see Table 14. No significant differences were recorded for any of the variables between trials for the back squat, deadlift, or CMJ trials. In contrast, significant differences were observed for bench press between trials 3-2 for displacement ( $F_{(1,12)} = 5.70$ ,  $p = 0.034$ ) with no significant differences recorded between other variables. The mean TE for all variables between trials was low to moderate (Table 15; range 0.6-8.8%), with SWC ranging from 1.7-7.7%; (back squat: 5.4-6.5%; bench press: 4.4-5.5%; deadlift: 1.7-7.7%; CMJ: 6.0%).

**Table 14.** Mean  $\pm$  SD for all trials (T) obtained via the GPT, with F score and p value following a repeated measures (1x3) one-way ANOVA.

	T1	T2	T3	F (1,12)	p value
<b><i>Back squat</i></b>					
Displacement (m)	0.591 $\pm$ 0.104	0.592 $\pm$ 0.107	0.587 $\pm$ 0.104	1.881	.195
Peak velocity (m $\cdot$ s <sup>-1</sup> )	0.849 $\pm$ 0.181	0.845 $\pm$ 0.164	0.840 $\pm$ 0.180	0.140	.715
Mean velocity (m $\cdot$ s <sup>-1</sup> )	0.477 $\pm$ 0.096	0.466 $\pm$ 0.089	0.468 $\pm$ 0.089	0.242	.632
Peak force (kN)	2.724 $\pm$ 0.588	2.651 $\pm$ 0.501	2.628 $\pm$ 0.510	2.484	.141
Mean force (kN)	1.926 $\pm$ 0.386	1.920 $\pm$ 0.381	1.921 $\pm$ 0.390	1.670	.221
<b><i>Bench press</i></b>					
Displacement (m)	0.382 $\pm$ 0.053	0.383 $\pm$ 0.053	0.396 $\pm$ 0.054	5.704	.034
Peak velocity (m $\cdot$ s <sup>-1</sup> )	0.480 $\pm$ 0.091	0.489 $\pm$ 0.089	0.468 $\pm$ 0.091	0.130	.725
Mean velocity (m $\cdot$ s <sup>-1</sup> )	0.369 $\pm$ 0.055	0.364 $\pm$ 0.056	0.374 $\pm$ 0.060	0.183	.676
<b><i>Deadlift</i></b>					
Displacement (m)	0.562 $\pm$ 0.034	0.568 $\pm$ 0.035	0.556 $\pm$ 0.033	1.805	.205
Peak velocity (m $\cdot$ s <sup>-1</sup> )	0.706 $\pm$ 0.119	0.725 $\pm$ 0.100	0.722 $\pm$ 0.109	0.502	.492
Mean velocity (m $\cdot$ s <sup>-1</sup> )	0.433 $\pm$ 0.034	0.431 $\pm$ 0.028	0.400 $\pm$ 0.022	0.622	.446
Peak force (kN)	1.503 $\pm$ 0.384	1.503 $\pm$ 0.392	1.505 $\pm$ 0.383	0.120	.916
Mean force (kN)	1.264 $\pm$ 0.311	1.257 $\pm$ 0.311	1.269 $\pm$ 0.308	0.468	.507
<b><i>CMJ</i></b>					
Height (m)	0.428 $\pm$ 0.089	0.431 $\pm$ 0.089	0.429 $\pm$ 0.084	0.120	.915

**Table 15.** Typical error displayed as a percentage (TE) across variables between trials (T).

	<b>TE T2-T1(%)</b>	<b>TE T3-T2 (%)</b>	<b>Mean TE (%)</b>	<b>SWC (%)</b>
<b><i>Back squat</i></b>				
Displacement	3.9 (2.9-5.9)	3.7 (2.7-5.6)	3.8 (3.0-5.3)	5.4
Peak velocity	8.9 (6.7-13.8)	7.1 (5.4-11.0)	8.1 (6.4-11.5)	6.3
Mean velocity	7.9 (5.9-12.3)	6.0 (4.5-9.3)	7.0 (5.6-10.0)	6.5
Peak force	5.2 (3.9-8.1)	3.1 (2.3-4.7)	4.3 (3.4-6.1)	6.0
Mean force	0.6 (0.4-0.9)	0.7 (0.5-1.0)	0.6 (0.5-0.9)	6.0
<b><i>Bench press</i></b>				
Displacement	3.4 (2.6-5.2)	2.4 (1.8-3.7)	3.0 (2.3-4.1)	4.4
Peak velocity	5.6 (4.2-8.6)	6.8 (5.1-10.4)	6.2 (4.9-8.7)	5.5
Mean velocity	7.1 (5.3-11.0)	7.7 (5.7-11.9)	7.4 (5.8-10.5)	5.2
<b><i>Deadlift</i></b>				
Displacement	1.9 (1.4-2.9)	2.0 (1.5-3.1)	2.0 (1.6-2.7)	2.0
Peak velocity	10.1 (7.5-15.6)	7.4 (5.5-11.4)	8.8 (7.0-12.5)	6.3
Mean velocity	7.3 (5.4-11.2)	6.6 (5.0-10.2)	7.0 (5.5-9.8)	6.5
Peak force	2.4 (1.8-3.6)	3.7 (2.8-5.7)	3.1 (2.5-4.4)	7.7
Mean force	1.5 (1.1-2.3)	1.6 (1.2-2.5)	1.6 (1.3-2.2)	7.4
<b><i>CMJ</i></b>				
Height	6.7 (5.0-10.4)	3.6 (2.7-5.6)	5.4 (4.3-7.7)	6.0

#### 4.4.3 Sample-size estimation

As the GPT derives all performance variables from time-displacement data, the power-analyses were only run on this variable across movements. For a simple test re-test or crossover design, minimum sample-sizes were estimated as four (back squat and bench press), and 11 (deadlift) to enable detection of 80% power. If a control group is implemented into the research, sample-size estimations increase to 16 (back squat), 15 (bench press), and 44 (deadlift). For CMJ, a test re-test design

would require a minimum of six participants, with inclusion of a control group increasing this to 25.

#### **4.4.4 Post-hoc power analyses**

Power analyses revealed that all study variables were under powered ( $<80\%$ ), including the back squat, bench press, deadlift, and CMJ ( $1 - \beta$ : 0.13; 0.48; 0.37; 0.13, respectively).

#### **4.5 Discussion**

This was the first study to explore the validity and reliability of the GPT against integrated criterion devices. The results demonstrate that the GPT is a valid device for determining kinetic and kinematic variables during resistance training movements (back squat, bench press, deadlift, and CMJ) in a trained population. Least products regression between the criterion devices and the GPT resulted in high  $R^2$  values ( $\geq 0.91$ ) for 20 of the 23 comparisons. Furthermore, the GPT produced low to moderate TE (0.6-8.8%) between visits, displaying generally high levels of intra-session reliability.

Within the data presented, the only measurements that showed a substantial difference between the GPT and criterion device were mean velocity for the deadlift. Moderate correlations were present for both GA ( $R^2 = 0.54$ ) and VM ( $R^2 = 0.69$ ) when compared directly to the GPT values. One practical explanation for this pertains to the sensitivity of the motion capture system (i.e. higher sampling frequency), as it was noted that with the deadlift an earlier concentric start point was often detected within the motion capture data.

During the initial start phase of the deadlift, the vertical movement of the bar is minimal, as supported by the strong correlations present between the GPT and motion capture system for deadlift displacement ( $R^2 \geq 0.92$ ). However, the addition of data points before the “true start” of the lift in the calculated velocity data, will result in the skewing of the mean. The mean takes the sum of all data points and divides this by the number of points. Therefore, the inclusion of extra data points, which have a low velocity (minimal change in the rate of displacement), results in a lower mean. This is apparent in the negative mean difference between the GPT and comparison values obtained from motion capture data (mean  $\pm$  SD: GPT:  $0.432 \pm 0.041 \text{ m}\cdot\text{s}^{-1}$ ; GA:  $0.332 \pm 0.054 \text{ m}\cdot\text{s}^{-1}$ ; VM:  $0.401 \pm 0.048 \text{ m}\cdot\text{s}^{-1}$ ).

One explanation may be associated with individual differences within the lift set-up. Tension is often placed upon the bar prior to initiation of the deadlift, causing the bar to flex or rotate (Hales, 2010). This would cause the GA (centred for the deadlift) and/or the VM to appear to displace vertically, triggering the data analysis process to register premature movement, prior to the GPT tether unwinding. This implies that the reported errors are due to the process of identifying the beginning of the movement, rather than the validity of the GPT. No current literature is available on the validity of an LPT when measuring mean velocity of a deadlift, meaning there is little evidence to provide support to this theory. Further research may wish to explore the role of the different methods of lift start identification on outcome variables.

With the exception of the mean velocity of the deadlift, the validity assessments have all shown strong correlations between the GPT and criterion measures for kinematic variables. This appears to agree with similar research which has explored the validity of kinematic measures obtained via other commercially available LPTs.

One such study investigated the validity of the Tendo Weightlifting Analyser during free-weight back squat and bench press (Garnacho-Castano, Lopez-Lastra, & Mate-Munoz, 2015). Results obtained from the LPT were validated against an isoinertial dynamometer, with high correlations for both peak and mean velocity reported,  $R^2 = 0.92$  and  $0.96$ , respectively. These strong correlations show comparable results and provide further evidence for LPTs as a suitable monitoring tool for kinematic performance variables.

The kinetic variables calculated from the GPT are all derived from the collected position data. Differentiation causes error in a signal to be magnified, therefore care should be taken to minimise error in collected data. The GAP employs a down sampling method to minimise these potential errors. Strong correlations were found for peak and mean force of the squat and deadlift trials ( $R^2 \geq 0.94$ ) suggesting the process of differentiation did not result in poorer results. Crewther et al (2011b) explored the validity of kinetic variables during weighted squat jumps collected using the GPT and force plate. Moderate correlations were reported ( $R^2 = 0.59-0.87$ ) following comparisons between collection methods. Rather than increased error due to data processing, it was suggested that the lower values reported ( $R^2 = 0.59$ ; obtained during 20 kg jumps), were due to horizontal bar movement, which was reduced as resistance was increased (40 kg:  $R^2 = 0.83$ ; 60 kg and 80 kg:  $R^2 = 0.87$ ). During this study, the GPT was attached to the end of the bar, increasing the potential for horizontal sway during jumping actions at lower resistances. While a similar attachment site was used in the present study, the inclusion of greater resistance, and therefore, the removal of the ballistic nature of the movement, likely decreased the potential for horizontal sway, thus increasing correlations between measurement devices (peak force:  $R^2 = 0.97-0.99$ ; mean force:  $R^2 = 0.94-0.99$ ).

It is worth considering that the data collected via the GPT is that of the movement of the tether, meaning results can differ depending on lift technique (e.g. horizontal bar movement) and tether attachment site. It is therefore recommended that care be taken when selecting attachment sites, particularly at lower resistances, or when ballistic movements are employed, as this may lead to a greater presence of error and thus skewing of data. Future research utilising similar protocols should ensure GPT attachment sites are marked and remain consistent throughout the course of data collection, as within this study, with an aim of reducing potential error between trials / visits. Where possible the tether should be attached as close to the centre of the bar as possible as this will limit the potential for horizontal sway to impact on the data.

The second aim of this study was to establish the test-retest reliability of the GPT. For back squat, deadlift, and CMJ, the lack of significant differences and low to moderate TE suggest that the GPT is a reliable tool for collecting performance variables of resistance trained individuals performing these tasks. To date, no other research is available to provide evidence as to whether the results for these movements are comparable across other LPTs or participant groups. As such, it is suggested that future research further explores the test re-test reliability associated with the GPT.

Alongside TE, calculated SWC provides important information about the use of a device over repeated trials. If SWC is higher than the reported between trial TE, then researchers and practitioners have confidence that any change that occurs above the SWC has occurred outside of potential whole system error and as such represents a meaningful variation. If SWC is lower than TE, practitioners need to



ensure future studies implementing such variables as outcome measures are suitably powered or adopt a higher lower-limit of acceptance such as  $2 \times TE$  (Hopkins, 2000). Within the current data collection, SWC is generally higher than TE, meaning these values could be used to infer meaningful change, however in the instances where TE is greater than SWC care should be taken when interpreting future data.

Analysis of the bench press resulted in the presence of statistical difference between displacement between trials 3-2 only. While these results raise doubt regarding intra-visit reliability of the GPT for bench press specifically, the minimal TE between visits (3.0%), and the presence of no further statistical difference between derived measures alleviate these concerns. Furthermore, when reviewing the specific data set in question it becomes apparent that for one participant (P10), an anomaly was recorded due to a failed repetition. The final repetition of the final set was failed, resulting in the researcher spotting the participant, pulling the bar higher than would naturally occur, thus impacting upon the between-visit variability. Approximately 7 cm of extra displacement data were reported on this repetition, potentially explaining the variance in the average score reported. Data for visit one and two were within one SD of each other. Removal of this data point (all P10 bench press data) results in a non-significant finding following the ANOVA, confirming this explanation ( $F_{(1-12)} = 4.264$   $p = 0.06$ ). Importantly, while this would have negatively impacted upon the reliability data, the validity comparisons would have been unaffected as the criterion device was collecting data simultaneously and thus would have also recorded increased displacement.

While no research exists regarding the reliability of displacement when utilising LPT technology, a similar study explored the reliability of peak velocity obtained via a comparable device during repeated bench press trials (Tendo Weightlifting Analyser; Stock, Beck, DeFreitas & Dillon, 2011). Peak velocity was recorded between 10-90% 1RM, over two repeated visits. The results indicated that at lower resistances ( $\leq 70\%$  1RM), test-retest reliability was moderate to high (CV = 3.1-5.8%), however, as resistance increased ( $> 70\%$  1RM), relative consistency decreased (CV = 10.3-12.6%). The authors suggested that this reduced consistency was likely associated with the low movement velocity present during the higher resistance trials, the devices ability to detect small differences in displacement, and potential participant fatigue due to previous repetitions. Within the current research, the results presented produced lower values than those reported (CV = 6.2%) considering the resistance utilised (80% 1RM). This is potentially due to the precision of the GPTs displacement detection in relation to the Tendo Weightlifting Analyser (0.3 mm versus 10.0 mm, respectively), and the minimal stress placed on the subjects prior to their repetitions. These results provide evidence supporting the use of the GPT within the monitoring of kinetic variables.

#### **4.6 Conclusion**

The aims of this research were to investigate and establish the validity and reliability of the GPT. The results presented show that the GPT provides valid measures of displacement and subsequent derivatives across a range of common resistance training exercises, when performed by trained individuals. Furthermore, low to moderate TE outputs, following repeated trials, provide confidence that the GPT can be utilised to detect worthwhile changes in performance within a trained participant group. The results do suggest care should be taken when monitoring deadlift

performance, with peak velocity potentially offering a more robust measure than mean velocity. Future research may wish to investigate the source of the errors associated with the calculation of deadlift mean velocity, and the effect different methods of lift start identification have on this variable. Furthermore, as sample-size for future research has been estimated, researchers can use this information within the design subsequent research.

#### **4.6.1 Limitations and future research**

While the reported data and subsequent conclusions present a significant and novel contribution to the existing literature surrounding the use of the GPT, it is important to highlight and acknowledge the limitations associated with the current data collection.

- i. Firstly, it should be recognised that the results presented within the current study do not necessarily transfer to future research. Only a small quantity of resistance-based movements were assessed and additionally relatively high external loads were utilised. As such, care should be taken when interpreting the data with the aim of measuring different movements or loading strategies. As previously highlighted, it has been suggested that at lower loads, devices such as the GPT may produce increased error due to the placement of the tether attachment. Therefore, future research should endeavour to explore the associated validity across a wider loading spectrum.
- ii. In addition, the movements assessed within the current study all present a relatively linear movement pattern, reducing potential error due to

horizontal bar sway. When utilising the GPT within more ballistic style movements, such as jumps, throws, and Olympic weightlifting derivatives researchers should first establish the associated error. Future research should first establish the validity and associated reliability across a wider movement spectrum.

#### **4.6.2 Practical applications**

The high regression, low-moderate TE and SWC, and absence of significance across the majority of assessed variables indicates that the GPT is a valid and reliable applied data collection tool. While demonstrated to be not as sensitive as the integrated criterion methods, the additional information offered by the tool (e.g. peak, mean, and relative velocity, force, and power) exhibit the use of such a device within the applied setting. Use of such a device will enable practitioners to obtain information that is often limited to a labour intensive, lab-based environment. Furthermore, due to the ease of attachment, the GPT provides the practitioner with the advantage of limited set up prior to collection of different movements. The results, therefore, suggest that the linear position transducer offers a cost-effective, versatile, and valid means for the measurement of displacement and subsequent derivatives including peak and mean velocity and peak and mean force. Subsequent literature should begin to explore how these variables can be used to shape / inform a resistance training programme, and the impact their manipulation has on the witnessed adaptations.

## **5.0 Comparison of velocity-based and traditional percentage-based loading methods on maximal strength and power adaptations**

## 5.1 Preface

Within the previous study the validity and reliability of the GPT was established against integrated criterion measures, across a range of multi-joint compound movements. Specifically, it was demonstrated that the GPT offers a valid and reliable measure of displacement, and thus can confidently be used as a tool to assess both this variable and the associated derivatives such as MCV. This chapter implements the information presented within the previous chapter through direct utilisation of the GPT as a performance monitoring tool.

As previously discussed, the main aim of this thesis is to explore the use of real-time MCV as a method of dictating training load. This novel concept is yet to be explored within the literature, with researches instead focusing upon maximal velocity lifting (González-Badillo et al., 2015; González-Badillo et al., 2014; Ramírez et al., 2015). While such methods demonstrate the positive effect of such an approach, they do not utilise the strong relationship documented between MCV and relative load (González-Badillo & Sánchez-Medina, 2010). It is postulated that utilisation of such an approach will enable load modification to be made in real-time, with reference to the athlete's current state of fatigue and readiness to train. As such, the first intervention study within this thesis is designed to explore the use of MCV as a load dictation tool during a maximal strength training phase.

## 5.2 Introduction

The specific adaptive response to resistance training has been shown to be directly influenced by the configuration of a number of acute training variables, including loading magnitude, number of sets and repetitions, rest duration, exercise type and order, and movement velocity (Kraemer, 1983a, 1983b; Kraemer & Ratamess, 2004). While the optimal combination of these training variables remains an area of interest, it appears that the sub-categories of training volume and specifically relative intensity, are critical factors in determining the type and extent of resulting neuro-physiological adaptations (Kraemer & Ratamess, 2004).

The prescription of load within resistance training allows specific adaptations to be targeted, directly influencing the other training variables configuration with a programme. While various methods for determining training load exist, the most prevalent, traditionally referred to as PBT, prescribes relative sub-maximal loads from a previously established 1-RM. This method is widely used within both applied and theoretical strength and conditioning and has been shown to be valid and reliable across a range of populations (Faigenbaum et al., 2012; Seo et al., 2012; Verdijk et al., 2009). However, as maximal strength has been theorised to fluctuate daily due to fatigue (Jovanović & Flanagan, 2014), and significantly increase / decrease due to continuous training / de-training, the method of prescribing load arbitrarily on potentially outdated 1-RMs has been questioned (Blazevich, Cannavan, Coleman, & Horne, 2007; Izquierdo et al., 2007; Kubo et al., 2010).

Other methods, collectively referred to as autoregulatory, rely on an athlete's understanding of their perceived exertion (RPE), and / or RIR (Helms et al., 2016; Helms et al., 2017). These methods offer real-time load adjustment, based on an

athlete's perceived readiness to train. However, while these methods are considered valid and reliable with trained populations, they adjust load based on subjective input from the athlete, creating potential inconsistencies between athletes and sessions based on understanding and / or experience (Helms et al., 2016; Helms et al., 2017). Furthermore, while these methods facilitate load adaptation within training, they generally require a minimum number of repetitions to be completed prior to interpretation, potentially fatiguing participants prior to load modification. Completing repetitions while fatigued, or with a non-optimal load, may not optimise the neuromuscular stimulus required to promote targeted adaptation (Banyard et al., 2018). Numerous researchers have shown how strength training in a fatigued state does not lead to significant increases in maximal strength when compared to training in a non-fatigued state, and can in fact have a detrimental effect on subsequent performance (Folland, Irish, Roberts, Tarr, & Jones, 2002; Izquierdo et al., 2006b; Sampson & Groeller, 2016). Therefore, an alternative approach able to provide instantaneous repetition feedback, enabling objective load selection and modification, could augment adaptations through a reduction of training induced fatigue.

Recent advancements in kinematic measuring devices have led to the development of alternative loading methods based on the relationship documented between lift velocity and relative intensity (González-Badillo & Sánchez-Medina, 2010). Research has demonstrated that movement velocity, which is dependent on both the magnitude of the load, and the voluntary intent to move it (Behm & Sale, 1993), influences neuromuscular stimuli, and thus the adaptations consequent to resistance training. This load-velocity relationship, commonly utilising MCV specifically, has been explored across a range of compound movements including



bench press, back squat, prone bench pull and military press (Balsalobre-Fernández et al., 2018a; Sánchez-Medina et al., 2013; Sánchez-Medina et al., 2017). Providing maximal concentric effort is applied throughout the movement, an inverse linear relationship is present between relative load and MCV. Furthermore, as repetitions continue during a consistent range of motion, MCV will decrease as muscular fatigue develops. This understanding has made it possible to determine the relative load during a given movement in relation to an athlete's current daily maximum and their MCV, providing the load-velocity relationship for a given athlete (or group of athletes) has been established (Banyard et al., 2017b; González-Badillo & Sánchez-Medina, 2010; Jovanović & Flanagan, 2014). Such findings have opened up the possibility of real-time monitoring of relative load, enabling specific adaptations to be targeted, factoring in training fatigue and strength fluctuations, as repetitions, sets, and periodisation progresses (Banyard et al., 2018).

Importantly, while the relationship between relative load and MCV has been shown to be reliable across repeat visits with trained athletes (Banyard et al., 2017b; González-Badillo & Sánchez-Medina, 2010), limited research has explored the use of integrating such profiles into periodised resistance training as a method of adjusting training load. Previous literature exploring such velocity-based approaches has generally utilised maximal concentric velocity, as opposed to optimal load prescription. Comparisons between these maximal velocity-based interventions and either, deliberate half velocity movements, or soccer specific training have led to significant improvements in maximal power output, maximal strength, 20 m sprinting ability, and jumping performance (González-Badillo et al., 2015; González-Badillo et al., 2014; Negra et al., 2016; Pareja-Blanco et al., 2014). However, despite these prospective improvements, methodological discrepancies

between the research designs limit the confidence surrounding the proposed conclusions. Issues such as lack of training variable control, participants training experience, use of a Smith Machine as opposed to free-weight movements, undisclosed maturation status of youth participants, and / or unreliable velocity collection methods are present throughout. Furthermore, while these articles have considered the impact of training at maximal concentric velocity, the relative load utilised was not manipulated based on the MCV output and thus no conclusions can be drawn based on the prescription of the load. It is worth noting that while the concept of using MCV within resistance training is becoming more prevalent, to date, no research has explored the effect of prescribing load based on this variable when compared to traditional PBT methods.

### **5.2.1 Research aims**

Despite the perceived and demonstrated importance of concentric lifting velocity and its relationship with optimal load prescription, no research currently exists comparing the effects of manipulating prescribed load on this variable. The lack of use of this performance variable within load selection is likely because until recently it was not possible to accurately measure velocity without resource intensive protocols. However, the validation of commercially available kinematic devices, such as the GPT, has facilitated the use of such methods within resistance training outside of the lab environment (Chapter 4.0). It is now possible for performance variables such as MCV to be calculated instantaneously enabling the manipulation of other training variables such as load to be based on real-time, objective information.

Therefore, the aim of the present research was twofold. Firstly, to establish whether use of the GPT, specifically recorded MCV, can be used as a method of dictating relative training load in real-time. Further to this, the effectiveness of utilising such a velocity-based approach on strength and power adaptations was explored. This was achieved through completion of an intervention comparing the effects of two different relative loading strategies (velocity-based and percentage-based) over a six-week training cycle. Addressing such aims would allow researchers and practitioners to make informed decisions about the use of the GPT, and specifically MCV, as a performance tool within athletic programme design. As previous literature has shown the LVP to be stable both between and within participants (González-Badillo & Sánchez-Medina, 2010), this aim was achieved via the implementation of generalised group-based velocity zones and stops into a periodised resistance training programme.

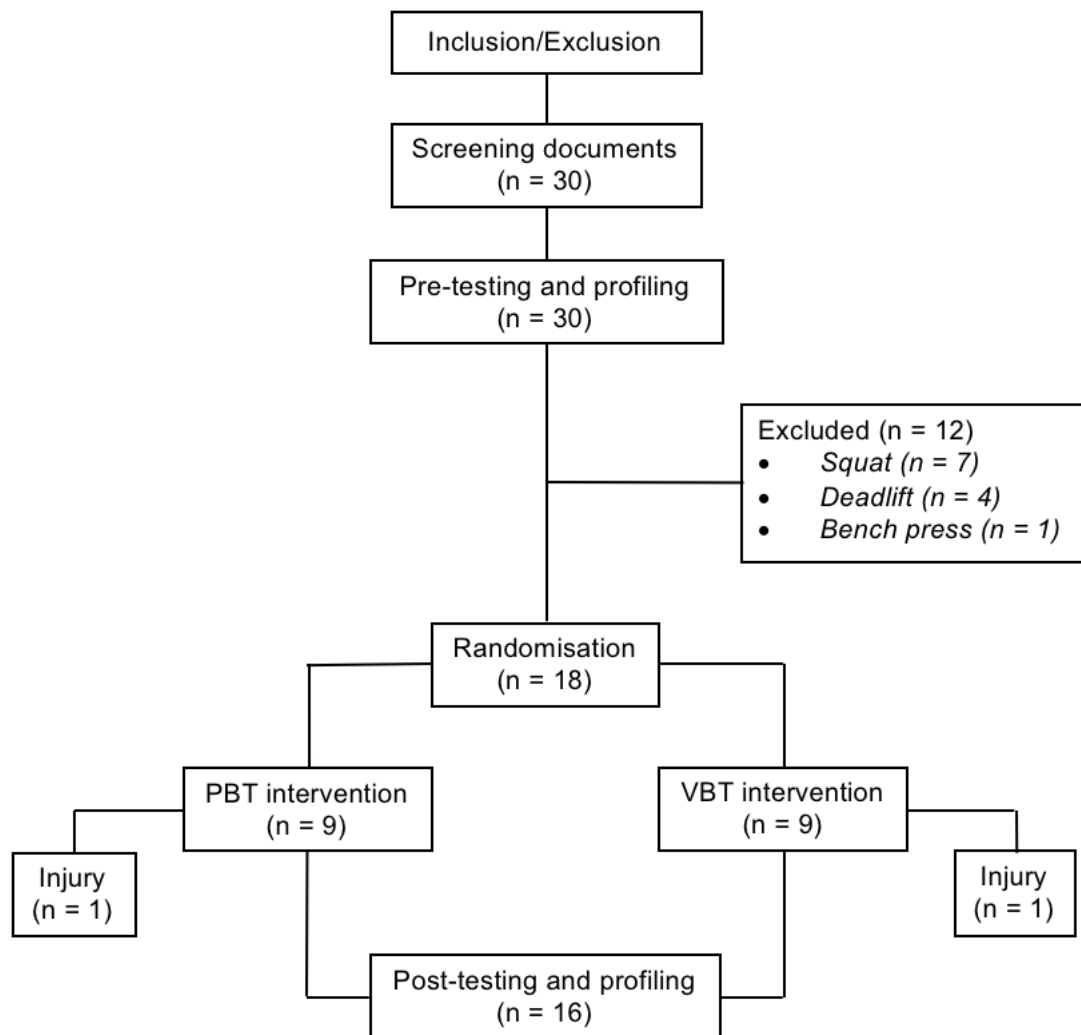
### **5.3 Research design**

The following section builds upon the already outlined general methods specified within section 3.0, and more specifically identifies the methods individual to this data collection.

#### **5.3.1 Experimental approach**

A randomised controlled research design was employed to explore the effects of manipulating prescribed load based on MCV when compared to traditional PBT methods. Following completion of screening documents, and prior to randomisation into intervention groups, participants were required to complete a series of 1-RMs and LVP protocols for back squat, bench press, strict overhead press, and deadlift as well as a CMJ protocol (Figure 10). Pre-testing and profiling were completed over

two separate days interspaced with a minimum of 72 hours rest. The order was fixed for all participants; day one consisted of 1-RM back squat and strict overhead press, day two included CMJ followed by 1-RM deadlift and bench press. Once pre-testing and profiling data were collected, participants were matched based on 1-RM assessment across all movements and randomly assigned into either the intervention (VBT; n = 8), or control (PBT; n = 8) group, via use of a random number generator. Participants were required to attend two supervised training sessions per week for the six-week training period. The location, time, and day of training sessions was fixed to each participant ( $\pm 1$  hour) for the six weeks. Upon arrival to the facility, participants were required to complete a standardised warm-up (section 3.5) before completion of the training session (outlined in section 5.3.5) with each session lasting between 60-90 minutes. Following completion of the mesocycle, and a minimum of 96 hours rest, the participants were required to complete the testing battery and velocity profiling in the same order as pre-testing.



**Figure 10.** Schematic representation of participant inclusion / exclusion process.

### 5.3.2 Inclusion criteria

It was required that all participants ( $n = 30$ ) had at least two years of resistance training experience, were familiar with 1-RM testing, were not taking performance enhancing drugs, and were free from musculoskeletal injury. Following questionnaire review, all participants were required to complete a series of 1-RM tests, including free weight full back squat, bench press, strict overhead press, and deadlift. Technique was assessed in line with previously explained methods (section 3.6.3), ensuring consistency both within and between participants.

### **5.3.3 Participants**

Thirty males originally volunteered to take part in the research study, however, due to injury ( $n = 2$ ), and failure to meet the inclusion criteria ( $n = 12$ ), sixteen resistance trained males were recruited and completed the training intervention (mean  $\pm$  SD, age:  $22.8 \pm 4.5$  years, stature:  $180.2 \pm 6.4$  cm, body mass:  $89.3 \pm 13.3$  kg). Participants 1-RM for the back squat, bench press, strict overhead press, and deadlift were  $140.2 \pm 26.0$  kg,  $107.7 \pm 18.2$  kg,  $61.3 \pm 8.7$  kg, and  $176.6 \pm 27.2$  kg, respectively (i.e.  $1.54 \pm 0.29$ ,  $1.13 \pm 0.20$ ,  $0.68 \pm 0.10$ , and  $1.95 \pm 0.30$ , respectively, when normalised to body mass).

### **5.3.4 Pre-testing and profiling**

For all assessed compound movements, 1-RM were established following traditionally employed procedures previously described (section 3.6.2). Movement technique was required to be consistent throughout all testing and training visits, in line with methods previously described (section 3.6.3). During each incremental load, the GPT was attached to the barbell, allowing calculation and recording of data variables such as MCV (Figure 6). Furthermore, the GPT was utilised to monitor depth during the back squat, ensuring participants maintained a consistent depth during all repetitions during the protocol over repeated visits. Following 1-RM testing, participants were required to complete a CMJ protocol in line with methods previously described (section 3.6.1).

### **5.3.5 Resistance training programmes**

For both training groups, relative training loads (% 1-RM), number of sets and repetitions, and inter-set rest time (3 minutes) were equal throughout the six-week intervention. Training programmes were initially designed with equated total volume

(sets x repetitions x relative load), however, as the VBT groups load and repetitions were dictated via real-time MCV monitoring, deviations from this equated volume occurred. This variance of total lifting volume was allowed to occur, as it was deemed a true representation of VBT, and how MCV impacts other training variables. For all repetitions within both intervention groups, participants were instructed to maintain eccentric control, before generating maximal force throughout the concentric phase of all compound lifts (back squat, bench press, strict overhead press, and deadlift). Strong verbal encouragement was provided to all participants to motivate them to give maximal effort throughout the sessions. The VBT group received an additional auditory tone to signal they were completing repetitions within the target velocity zone. The base for both training interventions (Table 16) was designed using methods previously described within the literature (Baker, 1995, 2007, 2013). The programme adopts a wave-like periodisation model, previously explained within section 3.7.

**Table 16.** Descriptive characteristics of the base training programme completed by both training interventions.

Session 1												
Week 1		Week 2		Week 3		Week 4		Week 5		Week 6		
Exercise	Reps	% 1-RM	Reps	% 1-RM	Reps	% 1-RM	Reps	% 1-RM	Reps	% 1-RM	Reps	% 1-RM
Back squat	8,8,8	70,70,70	8,6,5	70,75,80	6,5,3	75,80,85	8,6,5	70,75,80	6,5,3	78,85,90	5,3,2+	85,90,95
Bench press	8,8,8	70,70,70	8,6,5	70,75,80	6,5,3	75,80,85	8,6,5	70,75,80	6,5,3	78,85,90	5,3,2+	85,90,95
BB squat jump	2(3),2(3)	BM	2(3),2(3)	BM	2(3),2(3)	BM	2(3),2(3)	BM	2(3),2(3)	BM		
SOHP	8,8,8	70,70,70	8,6,5	70,75,80	6,5,3	75,80,85	8,6,5	70,75,80	6,5,3	78,85,90	5,3,2+	85,90,95
Deadlift											5,3,2+	85,90,95
Seated row	6,6,6	2 RIR	6,6,6	2 RIR	6,6,6	2 RIR	6,6,6	2 RIR	6,6,6	2 RIR		
Walking lunge	10,10,10		10,10,10		10,10,10		10,10,10		10,10,10			
Session 2												
Week 1		Week 2		Week 3		Week 4		Week 5		Week 6		
Exercise	Reps	% 1-RM	Reps	% 1-RM	Reps	% 1-RM	Reps	% 1-RM	Reps	% 1-RM	Reps	% 1-RM
Back squat	8,8,8	70,70,70	8,6,5	70,75,82	6,5,3+	75,83,88	8,6,5	70,75,82	6,4,2	78,88,92	4,4,4	70,70,70
Bench press	8,8,8	70,70,70	8,6,5	70,75,82	6,5,3+	75,83,88	8,6,5	70,75,82	6,4,2	78,88,92	4,4,4	70,70,70
BB squat jump	2(3),2(3)	BM	2(3),2(3)	BM	2(3),2(3)	BM	2(3),2(3)	BM	2(3),2(3)	BM		
SOHP											4,4,4	70,70,70
Deadlift	8,8,8	70,70,70	8,6,5	70,75,80	6,5,3	75,80,85	8,6,5	70,75,80	6,5,3	78,85,90	4,4,4	70,70,70
Plyo push-up	2(3),2(3)	BM	2(3),2(3)	BM	2(3),2(3)	BM	2(3),2(3)	BM	2(3),2(3)	BM		
BB hip thrust	8,8,8	+ BM	8,8,8	+ BM	8,8,8	+ BM	8,8,8	+ BM	8,8,8	+ BM		

\* BB: barbell; SOHP: strict overhead press; Plyo: plyometric; BM: body mass; 2(3): cluster set, 2 x 3 repetitions; RIR: repetitions in reserve; + BM: completed with body mass on the barbell.

\*\* Walking lunge load calculated (Ebben *et al.*, 2008):  $0.6 (6\text{-RM squat [kg]} \times 0.52) + 14.82 \text{ kg}$



#### *5.3.5.1 Velocity based training intervention*

A combination of velocity zones and velocity stops were used to integrate MCV monitoring into the base resistance training programme for the VBT group (section 3.7.1). For the four key movements within the programme (back squat, bench press, strict overhead press, and deadlift), MCV monitoring was utilised to dictate changes in the load lifted, and number of repetitions completed.

During each repetition, MCV was monitored in real-time via the GPT. Participants were provided with real-time auditory feedback based on the velocity of each repetition in relation to the predetermined zone / stop. If a repetition fell outside of the minimum threshold of the zone but was within the 20% acceptable drop-off from the mean, participants were instructed to complete a final repetition. If a repetition fell outside of the 20% drop-off, repetitions were stopped, and the set finished. The MCV of the completed repetitions (relative load <80% 1-RM: two repetitions; relative load >80% 1-RM: one repetition) was then reviewed in comparison to the velocity target, enabling objective load alterations to be made based on the performance of each preceding set.

#### **5.3.6 Statistical analysis**

For all variables, values are presented as means  $\pm$  SD. Data analysis were completed using SPSS 22.0 (Chicago, IL, USA), with the alpha level of significance set at  $\alpha = 0.05$ .

Independent sample *t*-tests were completed to examine the pre-training inter-group differences, as well as post-training total volume relationship. Paired-samples *t*-tests were completed to examine the intra-group percentage difference pre- to post-training. Two-way mixed (between-within) ANOVA, with Bonferroni *post-hoc*

comparisons, using one inter-factor (VBT vs. PBT) and one intra-factor (pre- vs. post-training), were conducted to examine the differences across all compound movements (back squat, bench press, strict overhead press, deadlift) and jump protocol between groups. Following completion of the ANOVA, G\*Power 3.1.9.4 (Düsseldorf, Germany) was used to calculate post-hoc achieved power, utilising  $\alpha$ , effect size (Cohen's  $d$ ; using  $\eta^2$ ), and sample size (Faul, Erdfelder, Lang, & Buchner, 2007). In addition, effect sizes (ES) were calculated according to Cohen's  $d$  (Cohen, 1988). Calculating ES allows the inter-group differences to be quantified irrespective of sample size. According to Hopkins (2010) ES can be classified as small ( $d = 0.21$ - $0.59$ ), moderate ( $d = 0.60$ - $1.19$ ), large ( $d = 1.20$ - $1.99$ ), and very large ( $\geq 2.0$ ), thus inferring that when group means don't differ by greater than 0.2 standard deviations, the difference is trivial.

Inferential statistics based on the magnitude of effects were calculated using a custom-built spreadsheet (Hopkins, 2007). The precision of the magnitude inference was set at 90% confidence limits, using a  $p$  value obtained via inter-group, independent  $t$ -tests. The smallest practical effect was calculated by multiplying the pre-training standard deviations by 0.2 (Sullivan & Feinn, 2012), and used to represent positive and negative threshold values. Mechanistic inferences were based on the relative relationship between the confidence interval range, and the smallest practical effect. The probability of the effect was evaluated according to the following scale: most unlikely:  $<0.5\%$ ; very unlikely:  $0.5$ - $5\%$ ; unlikely:  $5$ - $25\%$ ; possibly:  $25$ - $75\%$ ; likely:  $75$ - $95\%$ ; very likely:  $95$ - $99.5\%$ ; most likely:  $>99.5\%$  (Hopkins, 2007).

## **5.4 Results**

### **5.4.1 Pre-testing**

No significant differences between the VBT and PBT groups were reported pre-training for any variables analysed, including body mass, 1-RM strength, and CMJ height ( $p > 0.05$ ).

### **5.4.2 Strength assessments**

For both training groups, compliance within the programme was 100% of all scheduled sessions. Descriptive characteristics and ES are presented within Table 17. Training resulted in significant increases in maximal strength for back squat, bench press, strict overhead press, and deadlift for the VBT group ( $p < 0.01$ ; 9.3%; 8.4%; 6.5%; 6.4%, respectively), and back squat, bench press, and strict overhead press only, for the PBT group ( $p < 0.01$ ; 8.4%; 4.0%; 6.2%, respectively; Figure 11; 12). No significant group by time interaction effects were witnessed between training groups for the back squat, strict overhead press, or deadlift. A significant group by time effect ( $F_{(1,14)} = 11.50$ ,  $p = 0.004$ ) was recorded between groups for the bench press, indicating a significantly greater increase in maximal strength following the VBT intervention when compared to the PBT intervention. Inferential statistics revealed the VBT intervention to be “most likely” beneficial for the back squat, bench press, and strict overhead press, and “very likely” for the deadlift, as opposed to “most likely”, “likely”, “very likely” and “possibly” beneficial for the PBT group, respectively.

**Table 17.** Descriptive characteristics (mean  $\pm$  SD) and effect sizes of the velocity-based (VBT) and percentage-based (PBT) training groups, pre- to post-training.

	VBT			PBT		
	Pre	Post	ES	Pre	Post	ES
Back squat (kg)	147.8 $\pm$ 25.0	161.6 $\pm$ 27.1	0.59	131.9 $\pm$ 27.2	143.8 $\pm$ 24.7	0.44
Bench press (kg)	110.8 $\pm$ 15.2	118.9 $\pm$ 14.6	0.61	94.0 $\pm$ 17.8	98.4 $\pm$ 18.4	0.24
SOHP (kg)	64.6 $\pm$ 8.5	68.8 $\pm$ 7.9	0.52	58.1 $\pm$ 8.1	61.7 $\pm$ 8.9	0.41
Deadlift (kg)	176.4 $\pm$ 31.4	187.6 $\pm$ 30.0	0.38	176.9 $\pm$ 19.7	182.1 $\pm$ 19.7	0.22
CMJ (cm)	48.2 $\pm$ 10.2	50.6 $\pm$ 11.9	0.23	48.2 $\pm$ 7.6	48.7 $\pm$ 8.2	0.06

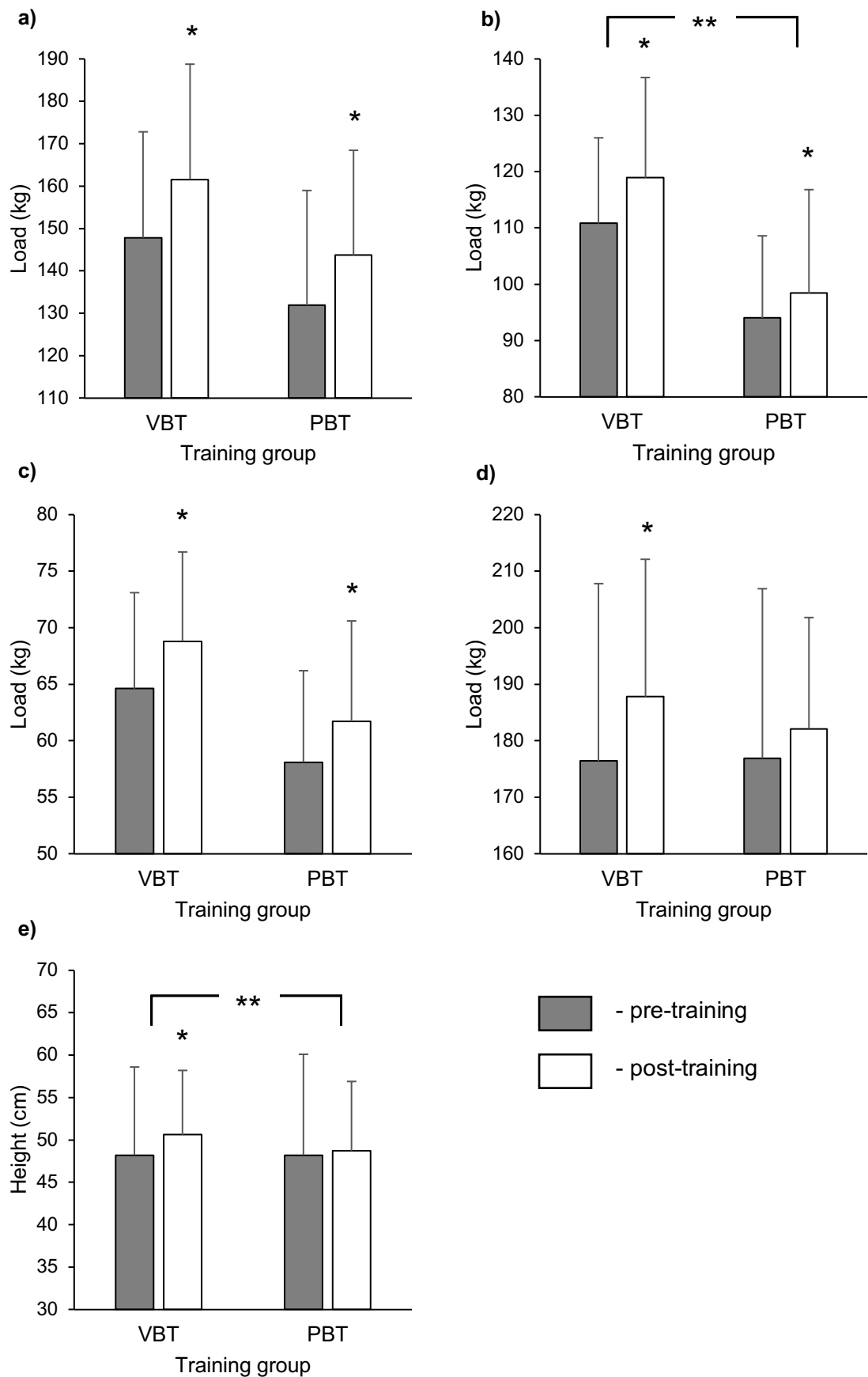
\* SOHP: strict overhead press; CMJ: countermovement jump; ES: effect size

### 5.4.3 Vertical jump assessment

A significant group by time effect ( $F_{(1,14)} = 7.14$ ,  $p = 0.02$ ) was present between training groups for CMJ (Figure 9). Training resulted in a significant increase in CMJ performance for the VBT group ( $p < 0.01$ ; 5.0%), but not the PBT group (1.0%). Inferential statistics showed the VBT intervention to be “possibly” beneficial, with the PBT intervention showing “most unlikely” benefits.

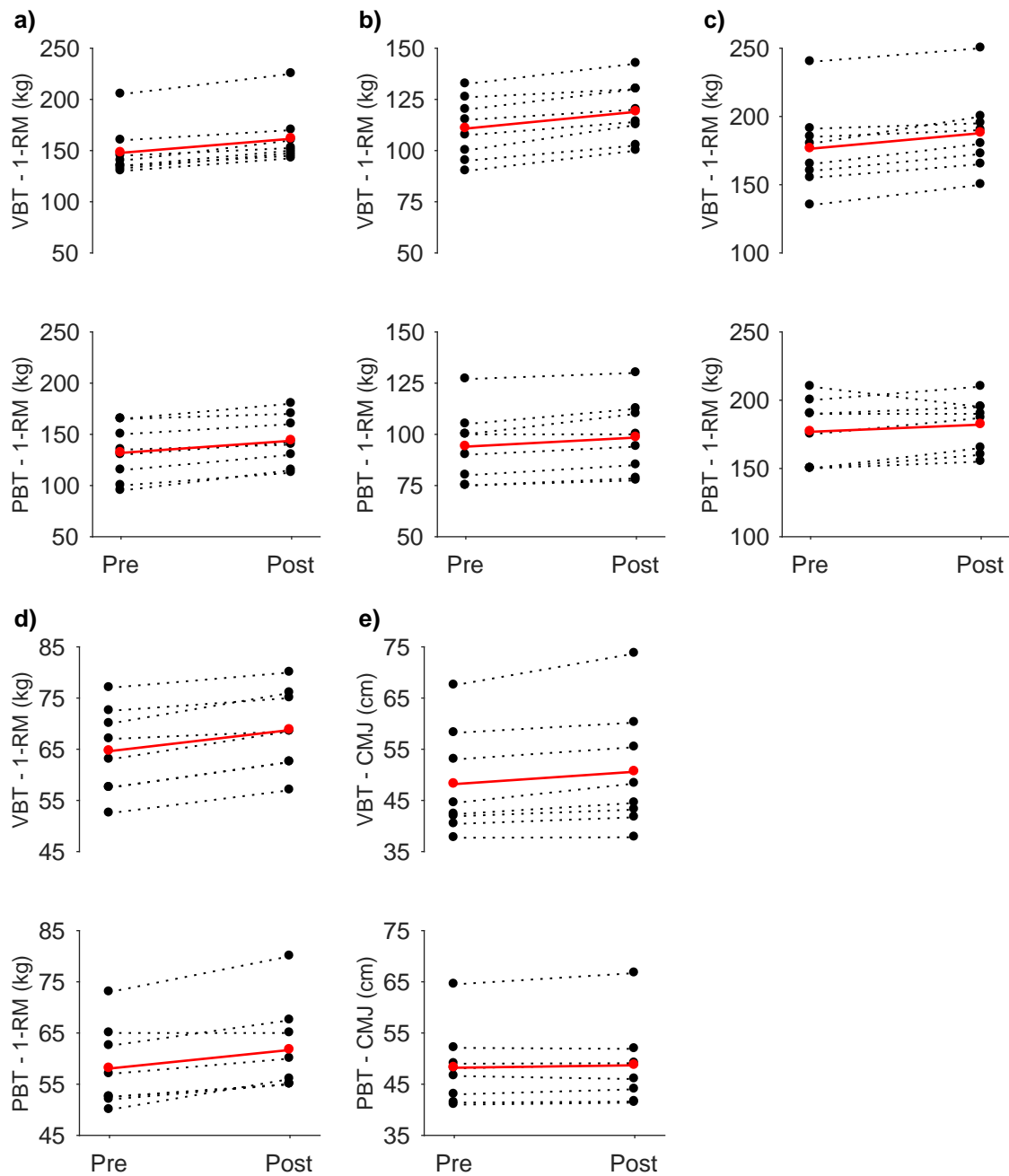
### 5.4.4 Post-hoc power analyses

Power analyses revealed that all study variables were under powered ( $<80\%$ ), including the back squat, bench press, strict overhead press, and deadlift ( $1 - \beta$ : 0.19; 0.70; 0.37; 0.08; 0.76, respectively).



\* : significant difference pre vs. post; \*\* : significant group by time effect.

**Figure 11.** Mean changes in back squat, bench press, strict overhead press, and deadlift 1-RM (a, b, c, d, respectively), and CMJ (e) following six weeks training.



\* VBT: velocity-based training; PBT: percentage-based training; CMJ: countermovement jump

**Figure 12.** Individual (dotted) and mean (red) changes for back squat, bench press, deadlift, and strict overhead press 1-RM (a, b, c, and d, respectively), and CMJ height (e), following six weeks training intervention.

#### 5.4.5 Intended vs. actual total volume

The VBT group completed significantly less volume for the back squat (- 8.8%), bench press (- 5.6%), and strict overhead press (- 5.9%) when compared to the PBT group (Table 18).

**Table 18.** Mean total volume completed for individual exercises and programme, created using relative load percentage in relation to pre-testing 1-RM data.

	VBT	PBT	Difference (%)	<i>p</i> value
Back squat	114896	125010	8.80	0.033
Bench press	117457	123982	5.56	0.019
SOHP	65742	69593	5.86	0.049
Deadlift	66827	67735	1.36	0.398
Mean volume	91231	96580	5.86	0.005

\* VBT: velocity-based training; PBT: percentage-based training; SOHP: strict overhead press

#### 5.5 Discussion

The aim of the present research was to investigate the impact of two different load prescription methods over a six-week resistance training intervention on strength and power in trained males. The data presented provides sufficient evidence to support the use of velocity-based loading methods within a resistance trained population for eliciting favourable improvements in maximal strength and vertical jump height when compared to traditional percentage-based loading methods. This finding is furthered when considering the significant reduction in total training volume completed by the velocity-based intervention over the full programme, specifically across the back squat, bench press, and strict overhead press exercises.

Findings from this research revealed training induced improvements in maximal strength and jump height following six weeks of VBT. Furthermore, with specific reference to individual differences (Figure 12), it becomes apparent that the all participants within the VBT group improved across all assessed variables. While all group mean data improved following the PBT intervention, only the back squat saw all individuals improve over time. For the remaining variables assessed (1-RM: bench press, deadlift, strict overhead press; CMJ height) at least one participant saw no improvement or a reduction in results. A potential explanation for this involves the increased training volume completed by this training intervention. As previously discussed (section 2.3.4.1), the greater accumulation of fatigue likely witnessed within the PBT group due to the increased training load lifted may explain the reduced output observed post-intervention testing. The taper employed within this study may not have optimised recovery within the PBT group who completed significantly greater volume, ultimately leading to a reduction in performance within the training-testing time frame. While this may be the case, the results within this study do demonstrate the positive impact adopting a VBT intervention has on strength and power, and more specifically how this translates to physical improvements within a short time frame.

While no direct comparative research is currently available, the results of this study are in agreement with previous investigations that reported increases in strength and / or vertical jump performance following similar VBT interventions. Pareja-Blanco et al. (2014) demonstrated the importance of velocity within resistance training, comparing maximal velocity to deliberate “half-velocity” training. Following a six-week intervention, back squat 1-RM significantly improved in both groups (maximal velocity: 18.0%; half-velocity: 9.7%), with a group by time trend approaching significance ( $p = 0.084$ ). Furthermore, significant performance



improvements were recorded for CMJ in the maximal velocity group only (+8.9%), producing a significant group by time interaction ( $p = 0.01$ ).

In a similar context, González-Badillo et al. (2014) reported significant increases in bench press 1-RM following six weeks of maximal velocity resistance training when compared to “half-velocity” training. Both groups (recreationally trained males;  $n = 20$ ) saw significant improvements (maximal velocity: 18.2%; half-velocity: 9.7%) pre- to post-training, with the maximal velocity group producing significantly greater increases ( $p < 0.05$ ). Further research by Pareja-Blanco et al. (2017) explored the outcome of eight weeks VBT, comparing the effects of velocity loss on 1-RM back squat and CMJ performance. Participants (healthy males;  $n = 22$ ) completed identical training programmes, only differing in velocity stop cut-off for each exercise (20% vs. 40%), and thus potential total repetitions. Significant maximal strength improvements were recorded ( $p < 0.01$ ) in both the 20%, and 40% group (18.0% vs. 13.4%, respectively), with no group by time effect recorded ( $p = 0.26$ ). Further significant improvements were witnessed in the 20% group for CMJ (9.5%), with a negligible increase witnessed in the 40% group (3.5%), resulting in a significant group by time effect ( $p < 0.05$ ).

While the training induced effects, and levels of percentage change reported in the aforementioned research are greater than those witnessed in the current investigation, this can be attributed to a number of methodological disparities. Firstly, all the investigations discussed used recreationally trained males (back squat 1-RM: Pareja-Blanco et al. (2014),  $92.1 \pm 10.4$  kg; Pareja-Blanco et al. (2017),  $106.2 \pm 13.0$  kg; bench press 1-RM: González-Badillo et al. (2014),  $74.9 \pm 13.8$  kg) as opposed to the current study, where resistance trained athletes were used (back squat 1-RM:  $140.2 \pm 26.0$  kg; bench press 1-RM:  $107.7 \pm 18.2$  kg). The training

status of individuals is known to have a significant effect on the improvements witnessed following a training intervention, specifically when reviewing strength increases (Ahtiainen, Pakarinen, Alen, Kraemer, & Häkkinen, 2003; Rhea et al., 2003; Schoenfeld, Wilson, Lowery, & Krieger, 2016). Lesser trained participants have been shown to generate significantly greater increases in strength when compared to trained individuals, directly impacting upon this comparison of data. This has been linked to increased neural alterations occurring rapidly in lesser trained participants, such as greater synchronisation and recruitment of motor units, improved rate coding, and greater reflex potentiation (Behm, 1995).

As participants in the current study were already resistance trained, these neural mechanistic changes are not witnessed to the same extent, impacting on the overall post-training improvements. Furthermore, in two of the comparative investigations (González-Badillo et al., 2014; Pareja-Blanco et al., 2014), control participants were instructed to deliberately slow their repetitions to that of ~50% maximal mean concentric velocity, which has been shown to have a significant effect on the subsequent performance measures (Pareja-Blanco et al., 2017). In the current study, both groups were instructed to maintain eccentric control before immediately lifting the load, utilising an approximate three second eccentric phase, minimal pause, followed by an immediate concentric phase. The only differing factor was the use of MCV to dictate load and repetitions within the VBT group.

The data presented further suggests that utilising velocity as a means to determine load and repetitions results in a significant reduction in required training volume to produce favourable improvements in maximal strength and jump performance. Pareja-Blanco et al. (2017) established how continued repetitions, and thus a decrease in lifting velocity, can alter the performance outcomes witnessed when

compared to a higher velocity programme, with lower total volume. Following completion of a VBT programme, with either low (20%; V20), or high (40%; V40) velocity stop cut-off, participants completed a 1-RM squat protocol. While within-subject pre- to post-training statistical differences were present for maximal strength ( $p < 0.001$ ; V20: 18.0% vs. V40: 13.4%), no group by time interaction was recorded. However, a significant difference was present between the total repetitions completed by each group ( $p < 0.01$ ; V20:  $185.9 \pm 22.2$  vs. V40:  $310.5 \pm 42.0$ ), and the total work completed ( $p < 0.001$ ; V20:  $127.5 \pm 15.2$  kJ vs. V40:  $200.6 \pm 47.1$  kJ), highlighting the importance of concentric mean velocity monitoring within resistance training. While the V20 group did not significantly improve measures of maximal strength over the V40 group, the lower volume, higher velocity training, elicited favourable performance outcomes while reducing the likeliness of training induced fatigue (Izquierdo-Gabarren, Expósito, Garcia-Pallares, Sánchez-Medina, et al., 2010). Within the present data collection, the VBT group lifted significantly less volume ( $p < 0.05$ ) than the PBT group, for back squat (8.8%), bench press (5.6%), strict overhead press (5.9%), and consequently, overall (5.9%), however produced similar (back squat, strict overhead press), or statistically greater (bench press) performance increases.

Training to muscular failure has been advocated as a fundamental principle of resistance training, based on the assumption that it produces significantly greater increments in measures of muscular strength and hypertrophy (Drinkwater et al., 2005; Rooney, Herbert, & Balnave, 1994). Within these investigations, while significantly greater strength gains were witnessed following training to muscular failure, repetition velocity was not monitored, nor was it intended to be maximal. As previous research has suggested (Behm & Sale, 1993), and contemporary research is now highlighting (González-Badillo et al., 2015; González-Badillo et al., 2014;

Pareja-Blanco et al., 2014; Pareja-Blanco et al., 2017; Sánchez-Medina & González-Badillo, 2011a), MCV monitoring is of principal importance when training for maximal strength and / or athletic performance (vertical / horizontal jump height / distance).

In agreement with the data presented within the current investigation, it has previously been suggested that training to muscular failure does not necessarily equate to significantly greater maximal strength improvements than training to non-failure (Davies, Orr, Halaki, & Hackett, 2016; Izquierdo-Gabarren et al., 2010). Within the current investigation, participants within the PBT group completed repetitions to failure in the final working set from the third training week, with the VBT group completing repetitions until velocity decreased beyond that of the velocity zone and / or stop. This meant that while the VBT group were completing a maximum repetition set, they would be stopped before true repetition failure due to concentric velocity monitoring. Previous literature has shown the compromising effect training to failure has on strength and power development when compared to non-failure training (Izquierdo-Gabarren et al., 2010). This reduction in resultant performance outcomes witnessed has been attributed to the increased development of residual fatigue within the neuromuscular system, directly impacting intra-session recovery. The presence of residue fatigue will likely cause a notable reduction in the quality of succeeding training sessions, compromising the ability of the neuromuscular system to rapidly develop force, and maintain training volume that can be completed effectively (Izquierdo-Gabarren et al., 2010).

While no research to date has actively explored the mechanistic changes that occur within the muscles following a VBT intervention, the use of rapid muscular contractions within resistance training has previously been investigated. Fast and

slow muscular contractions have been shown to exhibit a similar order of motor unit recruitment, commonly referred to as the size principle (Duchateau & Enoka, 2011). While this is the case, the absolute force level at which a specific motor unit is recruited has been shown to be affected by the speed of the associated contraction (Desmedt & Godaux, 1977). Research has shown that motor unit recruitment threshold decreases as the rate of force development increases, facilitating a greater recruitment of motor units during movements with greater contraction velocity, even when relative load is stable. The use of rapid muscular contractions has been shown to result in up to three times the recruitment of motor units, when compared to slower contractions producing the same force (Desmedt & Godaux, 1977). With regards to the current investigation, this could explain how the VBT group produced similar (back squat, strict overhead press), and statistically greater (bench press) improvements, when completing significantly less training volume over the intervention. The use of MCV within the VBT group limited the repetitions completed at slower velocities, as demonstrated by the lower total volume, limiting fatigue and potentially facilitating a greater recruitment of motor units. In comparison it can be theorised that due to potential non-optimal loading within the PBT group, repetitions may have been slower leading to a reduced overall recruitment, despite a potentially similar force output (Desmedt & Godaux, 1977; Kamen & Knight, 2004).

## **5.6 Conclusion**

In summary, the data presented within this investigation suggest that using velocity as a performance variable and means of dictating load may facilitate greater improvements in measures of maximal strength than traditional percentage-based loading methods. The combination of velocity zones and stops used provided a favourable environment for strength and power improvements within a resistance trained population. Furthermore, the results suggest that providing movements are

completed with an optimal load (dictated through MCV), fewer repetitions, and thus a lower total training volume is necessary to significantly improve maximal strength, and more pertinent to sporting performance, allow a positive transfer effect to movements including vertical jump.

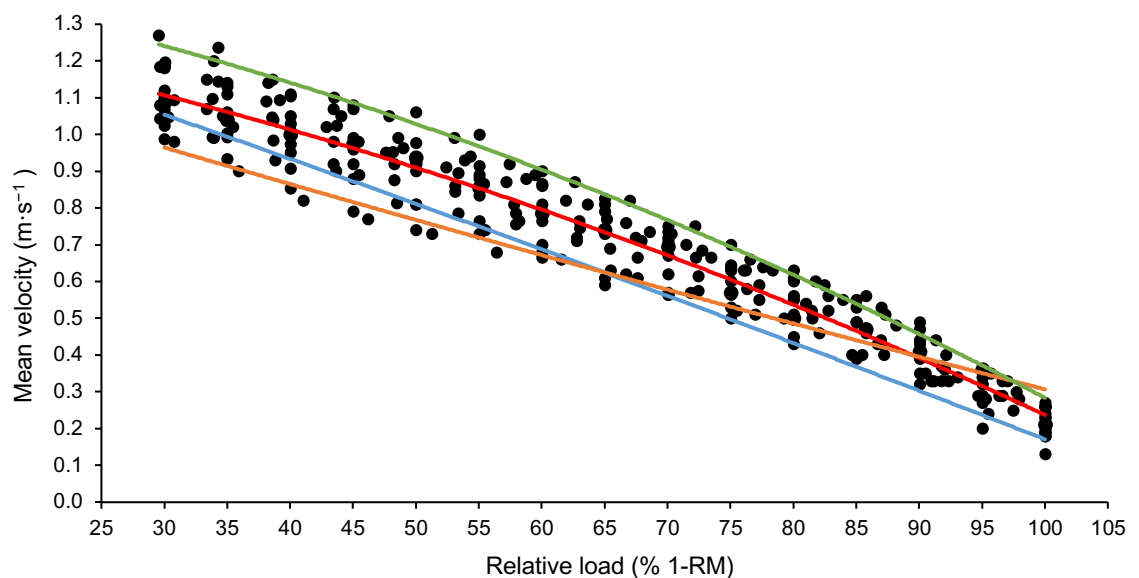
### **5.6.1 Limitations and future research**

When interpreting the presented results, it is important to consider the limitations associated within the current data collection.

- i. Firstly, it must be acknowledged that the mechanisms responsible for the observed improvements in maximal strength and power can only be theorised since muscle morphology, participant perceptions, and neural adaptations were not assessed. While this is the case, the current investigation did manage to ascertain the efficacy of utilising a velocity-based approach, within an applied setting, as a simple and effective training method for improving maximal strength and power.
- ii. Furthermore, while the process of utilising generalised group-based mean data as a method for dictating and modifying load produced significantly greater performance outcomes than percentage-based methods, individual differences may have affected the efficiency of such a method as recent literature has eluded (Balsalobre-Fernández et al., 2018a).

In further examination of the previous limitation, the data presented in Figure 13 displays the mean MCV for the participant group within this study for the back squat, and additional lines representing individual LVPs collected for specific participants. As can be seen from the example data highlighted, individual LVP characteristics can vary significantly, irrespective of relative strength and experience similarities. It

was a prerequisite that all participants had a similar resistance training background to try and limit the learning effect witnessed. Within this example participants achieved 1.58, 1.57, and 1.64 body mass to back squat ratio (green, blue, and orange, respectively). When considering the mean MCV range of values recorded at given relative percentages (70%: 0.20-0.36  $\text{m}\cdot\text{s}^{-1}$ ; 80%: 0.32-0.49  $\text{m}\cdot\text{s}^{-1}$ ; 90%: 0.43-0.63  $\text{m}\cdot\text{s}^{-1}$ ; 95%: 0.57-0.79  $\text{m}\cdot\text{s}^{-1}$ ), it becomes apparent that individual LVP may offer a more sensitive way of manipulating training load, leading to potentially greater performance outcomes.



**Figure 13.** Load velocity profiling data for back squat ( $n=16$ ). Lines representing mean value (red), and individual participants are displayed (P02: blue; P05: orange; P15: green).

Taken collectively, the results of this study demonstrate the effectiveness that a velocity-based loading approach had on measures of strength and power when compared to a more traditional percentage-based strategy. That being said, future research may wish to explore the efficacy of individual LVPs as a means to dictate and modify load when compared to either traditional PBT, or group LVPs as in the

current study. This may reduce the error reported, and thus increase effectiveness of such an approach, potentially increasing the performance outcomes witnessed.

### **5.6.2 Practical applications**

The results of this study contribute to the awareness surrounding VBT interventions within a resistance trained population. The data presented increases confidence surrounding the practical use of the GPT as a means of integrating velocity zones and stops within a periodised resistance training programme. Additionally, information on how these can be utilised to improve muscular strength and power is presented. Furthermore, prescribing and monitoring training intensity via real-time MCV tracking provides greater control over the prescribed training load, and the participant's current state of fatigue, without the need to perform multiple repetition maximum protocols. This gives practitioners a training variable enabling real-time monitoring on a rep-by-rep and / or set-by-set basis, reducing the risk of training induced fatigue, while allowing specific performance outcomes to be targeted through optimal loading.



## **6.0 Comparison of individual and group-based load-velocity profiling as a means to dictate training load over a six-week strength and power intervention**

## 6.1 Preface

The previous chapter explored the efficacy of utilising MCV as a means to dictate training intensity in real-time. This was achieved through direct comparison to a traditional percentage-based loading approach, utilising pre-training 1-RM over a six-week training cycle. Taken collectively, the results demonstrated the effectiveness of such an approach, producing similar or significantly greater adaptations despite a lower recorded training volume. As such a further exploration into velocity-based loading methods is warranted, specifically building on the limitations highlighted previously.

Within the previous chapter the use of generalised group-based LVPs were adopted. While this led to significant increases in strength and power, the presence of large individual differences was highlighted as a potential limitation. Participants were considered “resistance trained”, however large variances in the recorded LVP were apparent irrespective of absolute or relative strength. To address this, the current chapter aims to explore the use of such individualised LVPs by comparing their use to a group-based approach as in chapter 5.0. The use of individualised profiling may reduce the error witnessed, increasing the specificity of loading and thus the effectiveness of the programme, ultimately leading to increased physical adaptations. Furthermore, as target repetition velocity will be based on the individual athlete’s profile (within the intervention group), the target training volume should be achievable and consistent throughout.

## 6.2 Introduction

Due to the many factors that contribute to resistance training programming, it is difficult to determine the optimal dose and combination of acute training variables for targeted strength and power adaptations (Ahtiainen et al., 2005; Kraemer & Ratamess, 2004). However, research has demonstrated that lower volume training with optimal loading may lead to significantly greater adaptations than higher volume training where a greater number of repetitions are completed with a sub-optimal load (chapter 5.0; Banyard et al., 2018). As such, one of the main problems encountered by athletes and strength and conditioning practitioners revolves around the determination of optimal training load during periodised programming.

The external load applied during a given movement has the capacity to directly impact upon the physical adaptations witnessed, the fatigue induced, and subsequently the required recovery time between training bouts (Drew & Finch, 2016; Halson, 2014). As previously discussed (chapter 5.0), while numerous forms of dictating and manipulating load exist, no one method is without error, potentially leading to non-optimal load prescription. Traditional approaches utilise pre-training 1-RM assessments and individual feelings of perceived effort to modify and propose load over prolonged training cycles (Helms et al., 2016; Helms et al., 2017; Zourdos et al., 2016b). These methods, while widely utilised within the applied setting, rely on outdated assessments and subjective feedback, leading to a greater error potential. As such, contemporary literature has focused on alternative methods, providing coaches with a greater depth of objective data allowing informed choices to be made both within and between sessions (Banyard et al., 2018; García-Ramos et al., 2018; Pareja-Blanco et al., 2017; Sánchez-Medina et al., 2017).

At the centre of such methods is the advancement in commercially available devices such as the GPT. These systems have the capacity to validly and reliably collect and calculate multiple variables from each individual repetition (chapter 4.0). This has led to the development of novel training concepts involving otherwise difficult to obtain variables within the strength and conditioning environment. One such method (VBT) revolves around the use of MCV as a means to dictate training load based on a previously established LVP (Banyard et al., 2017b; González-Badillo & Sánchez-Medina, 2010; Sánchez-Medina et al., 2017). While limited research exists exploring this concept, such methods have been shown to be effective when compared to traditional percentage-based approaches over a strength training cycle (chapter 5.0).

Chapter 5.0 explored the effects of utilising MCV as a means to dictate load when compared to traditional percentage-based methods. Participants were strength matched and assigned to either a VBT or PBT group, with the only difference between groups being the method by which load was dictated. Traditional percentage-based methods were used for the PBT group, as opposed to MCV monitoring for the VBT group. Reported velocity was compared to previously established LVP data of the whole training group, with subsequent loads being increased or decreased depending on current performance. While the VBT method resulted in the same, or significantly greater adaptations in maximal strength and vertical jump height (despite a significantly lower total volume completion), the method of dictating load based on group profiles has recently been questioned due to the potential for large error to be present (Balsalobre-Fernández et al., 2018a).

Balsalobre-Fernández et al. (2018a) explored the LVP of thirty-nine resistance trained participants in the seated military-press exercise. Participants were required

to work up to a 1-RM from a standardised load (18 kg), in standardised increments (2.5 kg), with the mean achieved load ( $27.8 \pm 3.6$  kg) suggesting an average of four increments in total. The authors reported large disparities between the mean data set (group LVP) and those obtained by individuals (CV between 12.9% - 24.6%). While the fact both male and female athletes were included within the group LVP is acknowledged to have had a “likely-moderate effect” on the data, the authors do not acknowledge the significance of only collecting an average of four data points per participant (equating to approximately 11% 1-RM) before extrapolating eight for their analysis. The inclusion of such estimated data points may lead to greater error presence within the comparison between individual and group data sets, thus questioning the efficacy of the subsequent conclusions. Despite this, the authors conclude that while their results support the use of velocity monitoring as a means to infer load, the large reported disparities highlight the need for research to explore the idea of individualising training based on individual LVP data as opposed to generalised group equations.

Within chapter 5.0 (section 5.6.1), comparable data is presented, highlighting a limitation of the study. However, within this example the data reported is from resistance trained males with a similar relative and absolute 1-RM, alleviating the concern previously highlighted with data from Balsalobre-Fernández et al. (2018a). Furthermore, participants were required to complete a ‘full’ LVP for the back squat, working from 30% estimated 1-RM to true 1-RM over an average of 13 sets. The data presented within section 5.6.1 (Figure 13) further emphasises the need for future research to consider the individual differences likely present between similarly trained participants. Additionally, as it has been shown that different movements have significantly different LVPs associated with them (Figure 5; Table 4; Sánchez-Medina et al., 2013) , it can be assumed that the magnitude of the error will also

differ. For this reason, it is important to consider the movement assessed within the current investigation, the free-weight back squat, when comparing data from previous studies, as opposed to movements recruiting a vastly different musculature and utilising different movement patterns (Balsalobre-Fernández et al., 2018a).

Importantly, to date, only one other study has explored the use of MCV as a method of dictating load (Banyard et al., 2018). Participants were required to complete a free-weight back squat programme on four separate days, with load dictated via velocity-based or percentage-based methods. Fundamental to this study was the use of individual LVPs as a means of dictating training load, as opposed to group LVPs as previously discussed and utilised within chapter 5.0. The results demonstrated significantly greater attained mean and peak velocities, and well as significantly less induced mechanical stress (time under tension) when participants completed squats utilising a velocity-based loading approach. Despite this, participants completed the same level of mechanical work, and saw no reduction in peak or mean force or power over time. While the authors only investigated the acute kinematic and kinetic outputs of these loading methods, the data presented shows how utilising individual velocity-based loading approaches may lead to similar force and power outputs and significantly greater achievable movement velocities, while avoiding unnecessary mechanical stress, ultimately reducing fatigue.

### **6.2.1 Research aims**

Despite the apparent importance of MCV and its relationship with optimal load prescription, to date limited research exists exploring the concept of using MCV as a means to dictate load in real-time. Furthermore, currently no literature has explored the idea of individualising load prescription based on an individual LVP

over a training cycle. Within such a study, participant's load would be altered based on their performance in relation to their own previously established LVP, potentially removing the error previously reported when grouping data sets (chapter 5.0).

Therefore, the aim of the present investigation was to explore the effects of two differing velocity-based loading methods on measures of strength and power in resistance trained males. Such a study would provide a greater understanding surrounding the utilisation of MCV as a training variable, and further the knowledge on the best way to successfully implement it. Comparisons were drawn between an individual load-velocity profile (ILVP) and group load-velocity profile (GLVP) intervention, over a six-week lower body strength and power phase.

### **6.3 Research design**

The following section builds upon the already outlined general methods specified within section 3.0, and more specifically identifies the methods individual to this data collection.

#### **6.3.1 Experimental approach**

A randomised controlled research design was employed to explore the effects of two varying methods of manipulating prescribed intensity based on MCV monitoring. Following completion of screening documents, and prior to randomisation into intervention groups, participants were required to complete a series of jumping protocols (CMJ, SSJ, and SBJ), and 1-RM and load-velocity profiling protocols for the back squat (

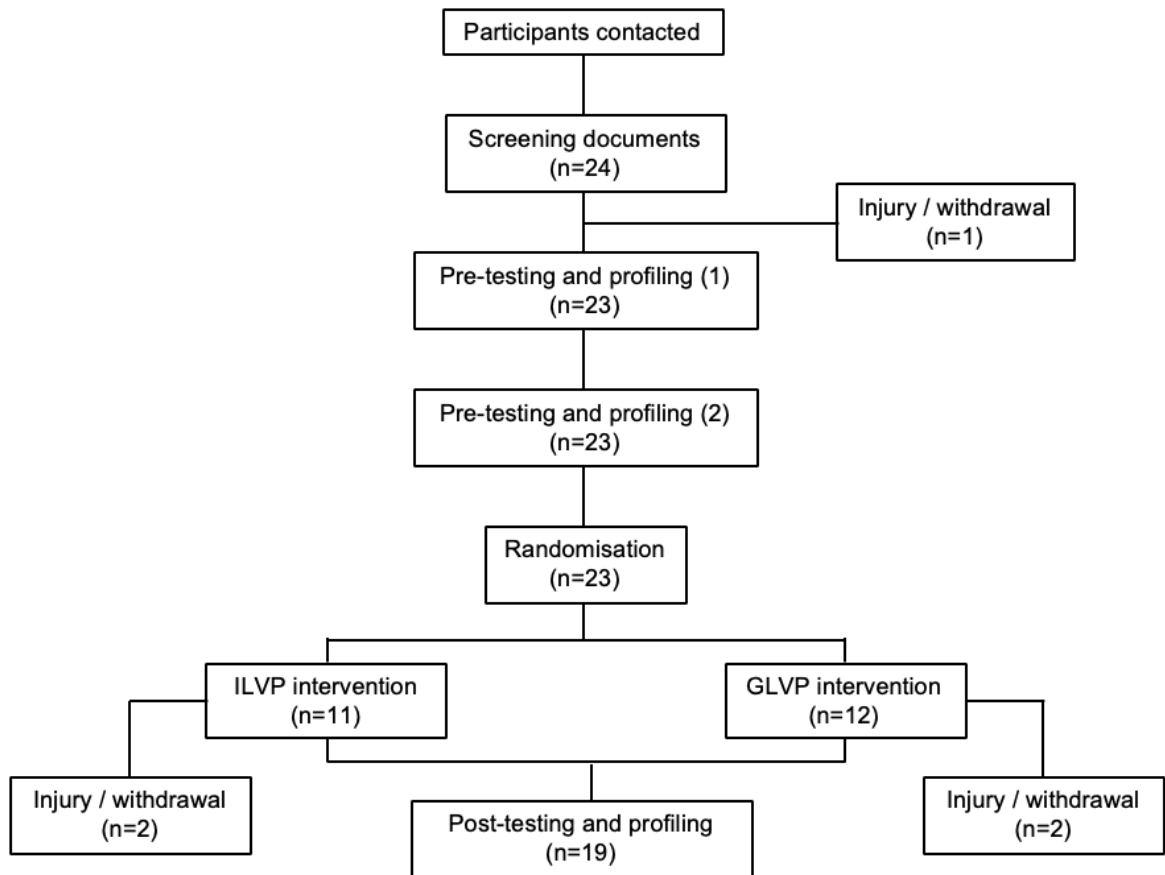
Figure 14). Pre-testing and profiling were completed over two separate days interspaced with a minimum of 120 hours rest. The order was fixed for all participants; day one consisted of all jumping protocols and 1-RM LVP for the back

squat, day two consisted of 1-RM LVP for back squat only (the same LVP was completed on both visits). Once pre-testing and profiling data were collected, participants were randomly assigned into either the intervention (ILVP;  $n = 9$ ), or control (GLVP;  $n = 10$ ) group, via use of a random number generator. Participants were required to attend two supervised training sessions per week for the six-week training period. The location, time, and day of training sessions was fixed to each participant ( $\pm 1$  hour) for the six weeks. Sessions were interspaced with a minimum of 72 hours rest. Upon arrival to the facility, participants were required to complete a standardised warm-up (section 3.5) before completion of the training session (outlined in section 6.3.5) with each session lasting between 60-90 minutes. Following completion of the mesocycle, and a minimum of 96 hours rest, the participants were required to complete the testing battery and velocity profiling in the same order as pre-testing.

### **6.3.2 Inclusion criteria**

It was required that all participants ( $n = 24$ ) had at least two years of resistance training experience, were familiar with the full back squat and 1-RM testing, were not taking performance enhancing drugs, and were free from musculoskeletal injury. Following questionnaire review, all participants were required to complete two 1-RM tests and load-velocity profiles for the free weight full back squat. Technique was assessed in line with previously explained methods (section 3.6.3), ensuring consistency both within and between participants.





**Figure 14.** Schematic representation of the participant journey through the intervention.

### 6.3.3 Participants

Twenty-four males originally volunteered to take part in the research study, however, due to injury / withdrawal ( $n = 5$ ), nineteen resistance trained males were recruited and completed the training intervention (mean  $\pm$  SD, age:  $23.6 \pm 3.7$  years, stature:  $182.7 \pm 5.1$  cm, body mass:  $92.2 \pm 8.7$  kg). Participant's 1-RM for the back squat was  $150.7 \pm 23.7$  kg, (i.e.  $1.64 \pm 0.19$ , when normalised to body mass).

### 6.3.4 Pre-testing and profiling

Prior to 1-RM testing, all participants were required to complete a series of jumping assessments including CMJ, SSJ, and SBJ. Protocol specifics have been previously described (section 3.6.1). Once all jumping protocols had been completed, back

squat 1-RM and load-velocity profiling were established following traditionally employed procedures previously described (section 3.6.2 and section 3.6.2.1). Movement technique was required to be consistent throughout all testing and training visits, in line with methods previously described (section 3.6.3). During each incremental load, the GPT was attached to the barbell, allowing calculation and recording of data variables such as MCV (Figure 6). Furthermore, the GPT was utilised to monitor depth during all repetitions of the back squat, ensuring participants maintained a consistent range of motion over repeated visits.

### **6.3.5 Resistance training programmes**

For both training groups, relative training load (% 1-RM), the number of sets and repetitions, and inter-set rest time (3 minutes) were equal throughout the six-week intervention. Training programmes were initially designed with equated total volume (sets x repetitions x relative load) between groups, however, as load and repetitions were dictated via different real-time MCV monitoring methods, deviations from this equated volume occurred within both groups naturally. This variance of total lifting volume was allowed to occur, as it was deemed a true representation of the various methods employed and required to meet the aim of assessing individual and group profiling methods. For all repetitions within both intervention groups, participants were instructed to maintain eccentric control, before generating maximal force throughout the concentric phase. Strong verbal encouragement was provided to all participants to motivate them to give maximal effort throughout the sessions with both groups receiving an additional auditory tone to signal they were completing repetitions within the target velocity zone. The base for both training interventions (Table 19) was designed using methods previously described within the literature (Baker, 1995, 2007, 2013) and previously employed in chapter 5.0. The programme

adopts a wave-like periodisation model, previously explained in detail within section 3.7.

**Table 19.** Descriptive characteristics of the base training programme completed by both ILVP and GLVP training interventions.

Session 1												
Week 1		Week 2		Week 3		Week 4		Week 5		Week 6		
Exercise	Reps	% 1-RM	Reps	% 1-RM	Reps	% 1-RM	Reps	% 1-RM	Reps	% 1-RM	Reps	% 1-RM
Box Jump **	5,5,5	BM	4,4,4	BM	3,3,3	BM	5,5,5	BM	4,4,4	BM	3,3,3	BM
Back squat	8,8,8	70,70,70	8,6,5	70,75,80	6,5,3	75,80,85	8,6,5	70,75,80	6,5,3	78,85,90	5,3,2+	85,90,95
RDL	8,8,8	***	8,8,8	***	8,8,8	***	8,8,8	***	8,8,8	***	8,8,8	***
Walking lunge	8,8,8	****	8,8,8	****	8,8,8	****	8,8,8	****	8,8,8	****	8,8,8	****
Session 2												
Week 1		Week 2		Week 3		Week 4		Week 5		Week 6		
Exercise	Reps	% 1-RM	Reps	% 1-RM	Reps	% 1-RM	Reps	% 1-RM	Reps	% 1-RM	Reps	% 1-RM
Box Jump **	5,5,5	BW	4,4,4	BW	3,3,3	BW	5,5,5	BW	4,4,4	BW	3,3,3	BW
Back squat	8,8,8	70,70,70	8,6,5	70,75,82	6,5,3+	75,83,88	8,6,5	70,75,82	6,4,2	78,88,92	4,4,4	50,50,50
Nordic curl	5,5,5	BM	5,5,5	BM	5,5,5	BM	5,5,5	BM	5,5,5	BM	3,3,3	BM
BB step-up	8,8,8	*****	8,8,8	*****	8,8,8	*****	8,8,8	*****	8,8,8	*****	8,8,8	*****

\* RDL: Romanian deadlift; BB: barbell; BM: body mass

\*\* Box jump height was initially set at mid-thigh, however increased/decreased based on performance each session

\*\*\* RDL load calculated at 50% 1-RM back squat

\*\*\*\* Walking lunge load calculated (Ebben *et al.*, 2008):  $0.6 (6\text{-RM squat [kg]} \cdot 0.52) + 14.82 \text{ kg}$

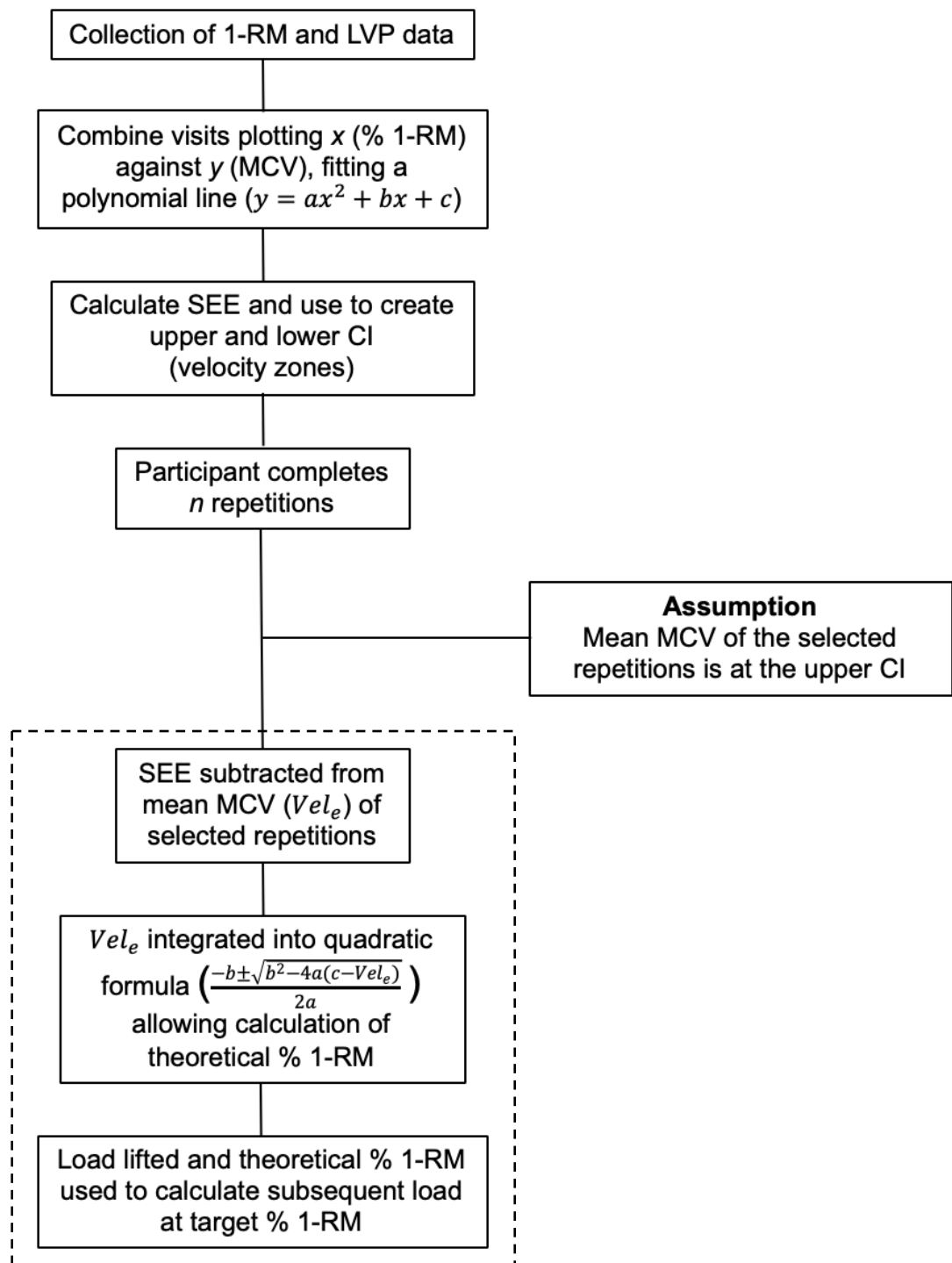
\*\*\*\*\* BB step-up load calculated at 30% 1-RM back squat, with step up so knee at knee at 90°

#### *6.3.5.1 Velocity based training interventions*

A combination of velocity zones and velocity stops were used to integrate MCV monitoring into the base resistance training programme for both intervention groups (section 3.7.1). For the main compound movement within the programme (back squat), MCV monitoring was utilised to dictate changes in the load lifted, and number of repetitions completed. For the ILVP group, load and repetitions were dictated based on individual data collected during the initial 1-RM and load-velocity profiling collections. This meant that load alterations were specific to the participant and their pre-training performance. In comparison, for the GLVP intervention, data were combined from the pre-testing sessions (in the same way as chapter 5.0) and used to create a mean data line and associated range. This encompassed all participants' load-velocity data within the groups, and meant load was modified in relation to group averages.

The GPT was used to monitor MCV, enabling real-time auditory feedback to be provided to the participant during each repetition in relation to the target velocity (section 3.4.2). The total attempted repetitions were dictated in real-time based on performance of each preceding repetition. Subsequent load was dictated via input of achieved MCV into a custom written spreadsheet (Figure 15; Table 20). The number of repetitions used in the process was fixed based on the relative intensity and number of repetitions completed during the initial LVP (relative load <80% 1-RM: two repetitions; relative load >80% 1-RM: one repetition). During the process it was assumed that the completed repetitions used within the load dictation process were at the upper CI or velocity zone. This was due to the unfatigued state the participant would have completed these repetitions in and the effect this likely had

on attained MCV. Therefore, to ensure load allocation was based on the mean data, the calculated SEE was subtracted from the mean MCV prior to use of this variable.



**Figure 15.** Schematic representation depicting the process of utilising mean concentric velocity as a means of dictating load. See Table 20 for detailed breakdown of dashed section.

**Table 20.** Working example of velocity dictated load process with example participant data.

Known data	
Equation of the line:	$y = ax^2 + bx + c$
Equation of the line:	$y = -0.0001x^2 - 0.0035x + 1.2656$
Participant's 1-RM:	140 kg
Standard error (SEE):	0.031 m·s <sup>-1</sup>
Previous load (% 1-RM):	84 kg (60%)
Mean MCV of selected repetitions:	0.870 m·s <sup>-1</sup>
Subsequent target load	
Target load (TL) %:	70% 1-RM
Estimate based of traditional 1-RM:	98 kg
Calculation of subsequent target load	
<b>Process:</b>	<b>Working example (with known data):</b>
Mean MCV – SEE = Vel <sub>e</sub>	0.870 – 0.031 = 0.839
<b>Actual % 1-RM =</b>	<b>Actual % 1-RM =</b>
$\frac{-b \pm \sqrt{b^2 - 4a(c - \text{Vel}_e)}}{2a}$	$\frac{-0.0035 \pm \sqrt{0.0035^2 - 4 \times -0.0001 \times (1.2656 - 0.839)}}{2 \times -0.0001}$
	= 58.1%
<b>Subsequent load =</b>	<b>Subsequent load =</b>
$\frac{\text{Load lifted}}{\text{Actual \% 1RM}} \times \text{TL \%}$	$\frac{84}{58.1} \times 70$
	= 101.4 kg

Once each individual LVP was established, the collected MCV of a given set could be used to infer to subsequent load based on a relative target. The equation of the LVP line was used to obtain values for *a*, *b*, and *c*, with these values then input into

the quadratic equation, ensuring the error associated with that participant had been removed from 'c'. This enabled the "actual" relative load of the preceding set to be quantified, with this then being used to calculate the subsequent load based on the target percentage. This can be seen within the "calculation of subsequent target load" section of Table 20, using the known data.

### **6.3.6 Statistical analysis**

For all variables, values are presented as means  $\pm$  SD. Data analysis were completed using SPSS 22.0 (Chicago, IL, USA), with the alpha level for significance set at  $\alpha = 0.05$ .

Independent sample *t*-tests were completed to examine the pre-training inter-group differences, as well as post-training total volume relationship. Paired-samples *t*-tests were completed to examine the intra-group percentage difference pre- to post-training. Two-way mixed (between-within) ANOVA, with Bonferroni *post-hoc* comparisons, using one inter-factor (ILVP vs. GLVP) and one intra-factor (pre- vs. post-training), were conducted to examine the differences across the back squat and all jump protocols (CMJ, SSJ, and SBJ) between groups. Following completion of the ANOVA, G\*Power 3.1.9.4 (Düsseldorf, Germany) was used to calculate post-hoc achieved power, utilising  $\alpha$ , effect size (Cohen's *d*; using  $\eta^2$ ), and sample size (Faul, Erdfelder, Lang, & Buchner, 2007). In addition, effect sizes (ES) were calculated according to Cohen's *d* (Cohen, 1988). Calculating ES allows the inter-group differences to be quantified irrespective of sample size. According to Hopkins (2010) ES can be classified as small ( $d = 0.21$ - $0.59$ ), moderate ( $d = 0.60$ - $1.19$ ), large ( $d = 1.20$ - $1.99$ ), and very large ( $\geq 2.0$ ), thus inferring that when group means don't differ by greater than 0.2 standard deviations, the difference is trivial.



Inferential statistics based on the magnitude of effects were calculated using a custom-built spreadsheet (Hopkins, 2007). The precision of the magnitude inference was set at 90% confidence limits, using a  $p$  value obtained via inter-group, independent  $t$ -tests. The smallest practical effect was calculated by multiplying the pre-training standard deviations by 0.2 (Sullivan & Feinn, 2012), and used to represent positive and negative threshold values. Mechanistic inferences were based on the relative relationship between the CI range, and the smallest practical effect. The probability of the effect was evaluated according to the following scale: most unlikely: <0.5%; very unlikely: 0.5-5%; unlikely: 5-25%; possibly: 25-75%; likely: 75-95%; very likely: 95–99.5%; most likely: >99.5% (Hopkins, 2007).

## **6.4 Results**

All scheduled sessions were completed by the participants across both intervention groups. Descriptive characteristics and ES are presented within Table 21 for both groups and all assessments.

### **6.4.1 Pre-testing**

No significant differences between groups were reported pre-training for any variables analysed, including body mass, 1-RM strength, and jump performance ( $p > 0.05$ ).

### **6.4.2 Strength assessments**

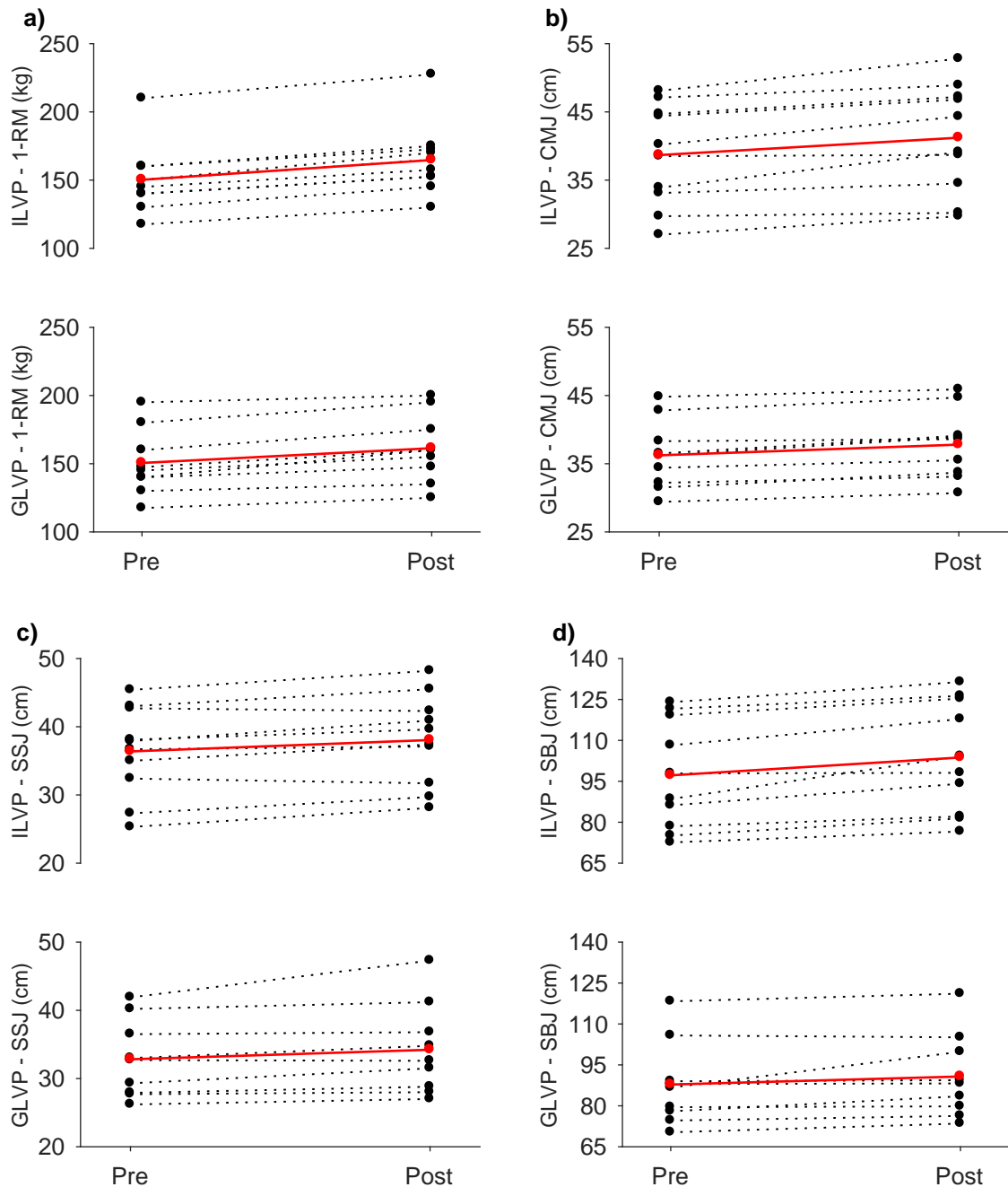
Training resulted in significant increases in back squat 1-RM for the ILVP and GLVP group ( $p < 0.01$ ; 9.7% and 7.2%, respectively; Figure 16). No significant group by time interaction effect was witnessed between training groups for the back squat ( $F_{(1,17)} = 3.97$   $p = 0.06$ ). Inferential statistics revealed the ILVP intervention to be

“most likely” (99.9%) beneficial for the back squat, compared to “very likely” (98.9%) for the GLVP intervention.

**Table 21.** Descriptive characteristics (mean  $\pm$  SD) and effect sizes of the individual (ILVP) and group (GLVP) load velocity training groups, pre- to post-training.

	ILVP			GLVP		
	Pre	Post	ES	Pre	Post	ES
Back squat (kg)	150.3 $\pm$ 24.7	164.8 $\pm$ 26.0	0.66	150.6 $\pm$ 24.3	161.4 $\pm$ 25.2	0.43
CMJ (cm)	38.7 $\pm$ 7.5	41.2 $\pm$ 8.0	0.32	36.2 $\pm$ 5.1	37.8 $\pm$ 5.1	0.21
SSJ (cm)	36.4 $\pm$ 6.6	38.1 $\pm$ 6.6	0.25	32.8 $\pm$ 5.7	34.2 $\pm$ 6.7	0.21
SBJ (cm)	97.2 $\pm$ 19.9	103.7 $\pm$ 20.5	0.32	87.8 $\pm$ 15.4	90.7 $\pm$ 15.4	0.19

\* CMJ: countermovement jump; SSJ: static squat jump; SBJ: standing broad jump; ES: effect size



\* ILVP: individual load-velocity profile; GLVP: group load-velocity profile; CMJ: countermovement jump; SSJ: static squat jump; SBJ: standing broad jump;

**Figure 16.** Individual (dotted) and mean (red) changes for back squat 1-RM, CMJ, SSJ, and SBJ performance (a, b, c, and d, respectively) following six weeks training intervention. All mean improvements are statistically significant ( $p < 0.05$ ) for both groups excluding the SBJ for the GLVP intervention.

### 6.4.3 Jump assessments

Training resulted in significant increases in CMJ, SSJ, and SBJ performance for the ILVP group ( $p < 0.01$ ; 6.6%, 4.6%, and 6.7%, respectively), and CMJ and SSJ only for the GLVP group ( $p < 0.05$ ; both 4.3%; Figure 16). No significant group by time interactions were reported between the groups (CMJ:  $F_{(1,17)} = 2.50$   $p = 0.13$ ; SSJ:  $F_{(1,17)} = 0.15$   $p = 0.71$ ; SBJ:  $F_{(1,17)} = 3.49$   $p = 0.08$ ). Inferential statistics demonstrated both the ILVP and GLVP interventions resulted in “likely” improvements in CMJ height (92.6% and 93.9%, respectively). Improvements documented in SSJ were “likely” (77.3%) associated with the ILVP intervention, as opposed to “possibly” for the GLVP group (56.3%). The SBJ performance was “likely” (92.5%) influenced following the ILVP intervention, as opposed to “possibly” (44.8%) for the GLVP intervention.

### 6.4.4 Post-hoc power analyses

Power analyses revealed that all study variables were under powered ( $<80\%$ ), including the back squat, CMJ, SSJ, and SBJ ( $1 - \beta$ : 0.51; 0.36; 0.07; 0.46, respectively).

### 6.4.5 Intended vs. actual total volume

Both the ILVP and GLVP intervention groups completed the same volume as originally programmed for the back squat (Table 22), with no significant difference reported between groups (0.87%;  $p = 0.632$ ).

**Table 22.** Mean total volume, completed repetitions, and load lifted between interventions, compared to programmed variables\*\*.

	<b>Difference (%)</b>	<b>p value</b>
<b>ILVP</b>		
<i>Total Volume</i>	1.06	0.276
<i>Repetitions</i>	0.60	0.425
<i>Load</i>	0.60	0.581
<b>GLVP</b>		
<i>Total volume</i>	0.19	0.909
<i>Repetitions</i>	0.77	0.240
<i>Load</i>	-0.37	0.826

\* ILVP: individual load-velocity profile; GLVP: group load-velocity profile

\*\* Data were compared to mean values of programmed intervention

## 6.5 Discussion

The aim of the present investigation was to explore the impact of two different velocity-based load prescription methods over a six-week resistance training intervention on measures of strength and power in trained males. The data presented provides sufficient evidence to support the use of such velocity-based loading methods within a resistance trained population for eliciting favourable improvements in maximal strength and jump performance. Furthermore, while no group by time interactions were reported between groups, the ILVP intervention did result in larger percentage increases and greater effect sizes across all variables assessed, indicating the worth of such an approach.

The main findings from this investigation were that a significant increase in back squat maximal strength and jumping performance was observed following six weeks of VBT. Both the ILVP and GLVP interventions led to statistically similar increases in back squat and CMJ performance as previously published data following a similar

training design (9.3% and 5.0%, respectively; chapter 5.0). While neither group led to significantly greater outcomes when compared between, the ILVP intervention did result in larger percentage increases across the range of assessments (ILVP vs. GLVP: back squat: 9.7% vs. 7.2%; CMJ: 6.6% vs. 4.3%; SSJ: 4.6% vs. 4.3%; SBJ: 6.7% vs. 3.4%), greater effect sizes (Table 21), and either the same (CMJ), or stronger (back squat, SSJ, and SBJ) inferential statistics for all assessed variables. These marginal improvements were observed despite no significant difference reported for completed repetitions, load lifted, or overall total volume between intervention groups or from pre-planned programming (Table 22).

While the improvements reported in maximal strength are important to discuss, this variable is not generally the target for athletic development, particularly during the later stages of periodisation (Bompa & Haff, 2009; Turner & Comfort, 2017). As previously discussed (section 2.2.1.2), while force generation is considered a necessity for many sports, an athlete's ability to exert this force within the shortest time frame is often considered more pertinent to success due to the time constraints of competitive sport (Haff & Nimphius, 2012; Stone, Moir, Glaister, & Sanders, 2002). As such, strength and conditioning practitioners are always seeking innovative training and loading methods facilitating optimal transfer to sports performance, often measures through jumping or sprinting assessments (Harries et al., 2012; Helms et al., 2018; Young, 2006). Within the current study the ILVP group displayed significant increases in both strength and power producing ability across all variables assessed, resulting in a greater magnitude of change over time than the GLVP group. This greater transfer between increased force production and RFD, in combination with the links between power-based movements such as jumps and other components such as linear speed and change-of-direction (Köklü,

Alemdaroğlu, Özkan, Koz, & Ersöz, 2015; Loturco et al., 2015; McFarland, Dawes, Elder, & Lockie, 2016), strengthens the overall findings of this study. Furthermore, it would appear that the method of dictating load via individualised LVPs leads to a greater transfer than group-based LVPs, providing greater confidence around the use of such methods.

The concept of individualisation is paramount to consider in the design of resistance training protocols in order to continually stimulate optimal adaptation over prolonged time periods (Borresen & Lambert, 2009; Helms et al., 2018; Kiely, 2012). Research has demonstrated improvements in training adaptation when individualised training programmes are employed over non-individualised approaches (Helms et al., 2018; Jones et al., 2016; Mann et al., 2010). Despite such findings, and the demonstrated importance of individualisation within resistance training, training load is still commonly prescribed based on pre-training 1-RM assessment (Fleck & Kraemer, 2014). As previously discussed (section 2.2.2.2), such methods offer minimal individualisation both within and between athletes and are open to error based on atypical performance during assessment (Ben et al., 2017; Fisher et al., 2011; Knowles et al., 2018; Perkins et al., 2001). As such, the method of prescribing load from such assessments may lead to non-optimal loading, ultimately reducing the physical improvements witnessed.

The novelty of this study is within the use of individualised LVPs as a method of dictating training load adjustments in real-time. As such, there is a lack of direct comparative research available from which the significant improvements can be cross-examined. However, as the foundation of such a method is developed based on the individualisation of training load, the results of this study will be compared to

other individualised loading methods such as RIR (Helms et al., 2016; Zourdos et al., 2016b). While direct comparisons cannot be made due to vastly different research designs, it will provide a greater understanding surrounding the efficacy of such an approach when compared to a widely cited alternative.

To date, only one study has implemented an RPE / RIR based loading approaching into resistance training when compared to traditional percentage-based methods (Helms et al., 2018). Within this study participants performed free weight back squat and bench press three times a week, with load dictated via traditional percentage-based methods or through use of individual athlete perceptions (RPE scale; Zourdos et al., 2016b). Following eight weeks of training, both groups displayed significant increases in strength ( $p < 0.001$ ) and muscular thickness ( $p < 0.01$ ) with no reported between-group difference. Specifically, 1-RM back squat increased by  $13.9 \pm 5.9$  kg and  $17.1 \pm 5.4$  kg, and 1-RM bench press by  $9.6 \pm 5.4$  kg and  $10.7 \pm 3.3$  kg for the percentage- and RPE-based loading methods, respectively. Additionally, small between-group ES and greater probability of change were noted for back squat (0.50; 79%, respectively) and bench press (0.28; 57%, respectively) favouring the RPE-based approach. Despite no apparent significant difference between loading methods, the authors concluded that the greater absolute change, stronger ES, and higher probability of change witnessed following the RPE-based loading approach demonstrate the worth of such loading methods. Interestingly, the significant improvement in strength and hypertrophy were witnessed despite the majority of training occurring outside of failure ranges. Athletes generally completed repetitions at a 6-7 RPE, shown to represent 3-4 RIR (Zourdos et al., 2016b). This further demonstrates the worth of such individualised loading methods, potentially removing the need to train to failure providing load prescription methods are optimal.



When comparing the magnitude of change following Helms et al., (2018) intervention to that of the present study, similar percentage improvements can be seen between studies. Within the current data collection, participants within the ILVP group improved free weight back squat performance by 9.7%, as opposed to 8.6% within the RPE-based loading group (Helms et al., 2018). One reason for the trivial difference in favour of individual velocity-based approaches may be due to discrepancies between initial starting strength values. Within the current study, participants within the ILVP group attained a 1-RM to body mass ratio of 1.68, whereas participants within the RPE study had a ratio of 1.82, despite achieving similar absolute values ( $149.6 \pm 23.2$  kg;  $143.7 \pm 24.9$  kg, respectively). This eludes to the fact that the participants within Helms et al., (2018) study were already trained to a higher standard, and thus improvements post intervention would be expected to be lower (Baker, 2013). Despite this, the presence of similar percentage increases following the ILVP intervention, despite only completing six weeks of training (as opposed to eight; Helms et al., 2018), support the concept of such loading approaches potentially offering greater optimisation of load than alternative individualised methods.

While no group by time interactions were present for any of the assessed variables pre- to post-intervention within the current data collection, the significance of the improvements, specifically within the ILVP group, should not be overlooked. When compared to traditional percentage-based loading methods completed with similarly trained athletes (1-RM to body mass ratio) over similar timescales, the magnitude of the documented improvements is better appreciated. For example, Hoffman et al. (2009) conducted research exploring the impact of 15 weeks periodised strength training on the 1-RM back squat and jump performance of resistance trained

athletes. Within this study, the participants attained a 1-RM to body mass ratio of 1.56 pre-intervention. At the end of the training intervention 1-RM back squat had significantly improved by an average of 11.1% ( $p < 0.05$ ). While the improvements in maximal strength witnessed are greater than those displayed within the current study (11.1% vs. 9.7%, respectively), it is important to highlight that the participants training programme accrued over twice the training weeks, and more specifically, 2.5 times the training sessions. Despite this greater exposure to a training stimulus, and a similar initial training status, the ILVP group within the current study achieved comparable strength improvements. Such findings demonstrate the potential of individualised velocity-based loading approaches to augment the strength improvements witnessed in significantly shorter time periods. However, as this research did not explore the longitudinal influence of such methods (i.e. > 6 weeks), such things can only be hypothesised.

As previously discussed, the optimisation of resistance training is largely dependent on the optimal configuration of the acute training variables over time (Kraemer, 1983a, 1983b). Specifically, a periodic alteration in training intensity is advocated to be of paramount importance when seeking to optimise physiological strain, ultimately inducing positive alterations in muscular strength (Jenkins et al., 2015; Schoenfeld et al., 2015b). It is widely acknowledged that the force applied during a contraction impacts upon the recruitment of motor units, with said force influenced by both the external load and velocity of the contraction (Jenkins et al., 2015). In a similar way to that of chapter 5.0, the use of MCV as a load dictating variable within the current study may positively impact upon the recruitment of higher threshold motor units by maintaining a high velocity output throughout (Desmedt & Godaux, 1977; Nardone, Romano, & Schieppati, 1989). While both training interventions

within the current study utilised a velocity-based approach, the ILVP groups loading was specific to their individual LVP. This may have positively impacted upon the specificity of the load, allowing a better adaptation of training intensity both within and between sessions. In comparison, while the GLVP load dictation method may lead to greater specificity than more traditional percentage-based methods (chapter 5.0), it may not be as sensitive as ILVP, explaining the variance witnessed in the results. As such, the method of individualising load, based on ILVPs may increase the ability of athletes to maintain higher velocities, ultimately increasing force output over repeated repetitions, and thus positively influencing motor unit recruitment.

## **6.6 Conclusion**

In conclusion, the data presented within this study demonstrates the potential impact of utilising a velocity-based loading approach on measures of maximal strength and power. Specifically, the results suggest that use of individualised velocity-based loading may offer a greater magnitude of change for athletes when compared to a group-based approach. As previous research has already alluded to the fact that such group-based approaches may lead to significantly greater adaptations than percentage-based approaches (chapter 5.0), it could be theorised that the same significance would be present for individual-based approaches. Furthermore, the data suggest that adopting an individualised approach may lead to a greater positive transfer to power-based movements, specifically vertical and horizontal jumps.

### **6.6.1 Limitations and future research**

The novel data presented within this chapter offers readers an insight into an otherwise unexplored aspect of VBT, specifically the use of ILVP as a means of

dictating training load. However, it is important to highlight the limitations within the data collection, enabling future research to build delimit these and further develop the understanding of such concepts.

- i. It must be acknowledged that the exclusion of a true control group (PBT) does limit the transferability of the conclusions. As no comparison between ILVP and traditional percentage-based methods is available, it is difficult to draw comparisons between such methods. While this is the case, as the control group within this study (GLVP) completed a very similar loading strategy as in chapter 5.0 (where PBT was the control group), indirect links can still be made between the loading methods. Future research should explore the use of individual velocity-based loading methods to percentage-based approaches to provide greater confidence around the proposed differences.
- ii. Additionally, the presented data can only be interpreted with reference to the specific movements tested, i.e. the full free-weight back squat. While similar adaptations may be present following different movements, the current data focuses specifically on the back squat. As such, future research should look to explore the impact of ILVP across a wider range of movements, specifically upper body and Olympic weightlifting derivatives.
- iii. A further consideration is the timescale over which the training was completed. While significant pre- to post-intervention data were collected, the training programme was only completed over a relatively short training

period. As such, it is difficult to deduce the likely impact of continuous training adopting such a loading method. While this does not detract from the significance of the findings, future research should explore the impact of including such loading methods over longer periods to further understand the potential benefits of utilising such an approach.

- iv. A final consideration is with regards to the sample size. While the participants within this study displayed a high level of resistance training experience, as demonstrated by their 1-RM to body mass ratio ( $1.64 \pm 0.19$ ), the total number of successful participants was still low ( $n = 19$ ). This may have impacted on the analysis carried out, specifically the two-way mixed ANOVA, where it can be noted the pre- to post-intervention data displayed a trend approaching significance for both back squat and SBJ ( $p = 0.06$ ;  $0.08$ , respectively). Had the study been sufficiently powered (section 6.4.4), the analysis may have yielded significant group-by-time interactions, strengthening the overall conclusions.

### **6.6.2 Practical applications**

The results of this study build upon those previously within this thesis and further demonstrate the potential benefits of adopting a velocity-based loading approach. While no significant differences were reported between groups pre- to post-intervention, the greater percentage increases, larger effect sizes, and strong inferential statistics do suggest utilising individual differences may potentiate greater adaptations. Such methods appear to provide a strength and conditioning practitioner with greater control over prescribing load, limiting the chances of unnecessary fatigue, while optimising the physical adaptations witnessed. Such an

approach allows objective feedback to be obtained on a rep-by-rep basis, ensuring each repetition is meaningful. The results further demonstrate how the GPT can be utilised to facilitate such an approach, requiring no additional time than the group-based approach previously explored. While the process of obtaining a full LVP may be time consuming, the demonstrated improvements witnessed help establish the worth of such methods.

## **7.0 General discussion**

## 7.1 Preface

The aims of this thesis were threefold; firstly, to ensure the GPT collected and reported valid and reliable data, specifically lift displacement and MCV. Once this had been established, the second aim of the thesis was to investigate the use of MCV as a means to dictate training load in real-time, utilising a group-based profiling approach over the course of the training intervention. The final aim of the thesis was to explore the efficacy of individualising training load adjustments based on individualised LVPs. These aims were achieved through the completion of three sequential data collections, as a part of a research design that increased in complexity by building on the limitations of previously collected data.

The data presented within this thesis offers some of the first experimental evidence regarding the use of MCV as a means to dictate training load in real-time. As such, the novel interventions and data presented contribute to the knowledge regarding the efficacy of VBT, specifically the concept of velocity-based loading. Collectively, the major findings arising from this thesis were that,

- i. The GPT provides both valid and reliable outputs of displacement and subsequent derivatives across a range of commonly practiced resistance training movements.
- ii. The individual load-velocity relationships of similarly trained and experienced athletes can be combined to create a group LVP, which is sensitive enough to prescribe load alterations in real-time.



- iii. This method of dictating training load based on the comparison between a previously established group LVP and real-time collected MCV data resulted in a reduction in required training volume to elicit similar or significantly greater improvements in strength and power.
- iv. Individual differences witnessed within athlete LVPs are not explicitly due to variances in absolute or relative maximal strength.
- v. Individualising load alterations based on these individualised LVPs has the potential to augment measures of strength and power when compared to a group-based approach with no associated increase in training volume.

## **7.2 Summary of key findings**

Whilst the GPT is widely utilised within research as a tool capable of detecting meaningful changes in velocity, force, power, and jump height (Argus et al., 2012; Argus, Gill, Keogh, & Hopkins, 2011b; De Lacey et al., 2014; Drinkwater et al., 2007c), conclusive data pertaining to the validity and reliability of the device is limited. Numerous researchers have investigated the validity and/or reliability of the GPT, however, a large proportion of reported data is misleading due to either a failure to compare to criterion devices (Banyard et al., 2017a), or the fact analyses were run on calculated variables (e.g. force, power) as opposed to the only measured variable of displacement (Askow et al., 2018; Banyard et al., 2017a; Crewther et al., 2011a). Additionally, while data is available on widely used multi-joint movements such as the back squat and bench press for similar, comparable devices, the majority of studies have restricted movements in the form of a Smith machine, as opposed to the more extensively applied free-weight versions

(Balsalobre-Fernández et al., 2018a; Pallarés et al., 2014; Sánchez-Medina et al., 2013; Sánchez-Medina et al., 2017). This is significant as in order to be able to confidently draw meaningful conclusions from subsequent research and prescribe practical recommendations to strength and conditioning professionals, the error present within the devices reported values must be acknowledged, specifically in relation to widely practiced movements.

The first novel aspect of this thesis was to address this issue, quantifying the error associated with the GPT over repeated visits and when compared to criterion devices. More specifically, study 1 (chapter 4.0) presents novel data on the only measured variable from the GPT (displacement), providing greater confidence surrounding the use of this device as an applied tool. While displacement is not commonly utilised as a performance variable, as it is the only measured variable it is essential any initial error is recognised. The results presented (section 4.4) demonstrate the GPTs ability to report valid measures of displacement and subsequent derivatives across a range of commonly practiced resistance training movements. Furthermore, the presence of low to moderate TE over repeated trials (0.6-8.8%) indicate the GPTs sensitivity in being able to detect worthwhile change within a training environment (chapter 5.0 and 6.0). While no comparative data exists with regards to the specific statistical analysis within this study, research by Askow et al. (2018) confirmed the high levels of agreement between the GPT and criterion devices. Specifically, small to trivial differences were reported and high intraclass correlation ( $> 0.91$ ) for all variables assessed for the back squat only (peak and mean; force, velocity, and power). Additionally, the reported TE and SWC presented within this thesis will allow researchers to consider sample size requirements of subsequent literature involving such variables. This data will help

rectify an often overlooked aspect of study design, contributing to the strength and transferability of conclusions and practical recommendations, specifically within the interpretation of significance testing and/or inferential statistics.

Specifically within this thesis, the validity and reliability data provide a solid foundation for subsequent studies, enabling balanced conclusions to be drawn, and strengthening the practical application of the findings. Whilst these results are significant and contribute to the current body of literature within this area, the wider importance of this thesis lies within the integration and utilisation of such devices into resistance training periodisation.

Within resistance training it is widely acknowledged that a periodic alteration in training load is paramount when targeting improvements in measures of maximal strength (Jenkins et al., 2015; Schoenfeld et al., 2015b). As such, the ability to objectively quantify, assess, and, monitor training load in real-time is pertinent to the strength and conditioning professional looking to maximise overall adaptations (Jenkins et al., 2015; Schoenfeld et al., 2015b). Despite this, the most common method of prescribing training load, percentage 1-RM, offers minimal individualisation both between and within sessions and participants (Fleck & Kraemer, 2014). Alternative methods of loading, devised to facilitate such individual responses, rely on subjective input from the athlete or coach, increasing potential individualisation by limiting objectiveness (Helms et al., 2017; Ormsbee et al., 2017; Zourdos et al., 2016b). As such, contemporary literature has focused on alternative loading methods, with the aim of increasing the efficacy surrounding individual load prescription and modification (Banyard et al., 2017b; Banyard et al., 2018; González-Badillo & Sánchez-Medina, 2010).

One such method focuses on the strong relationship documented between concentric lift velocity and relative load (Banyard et al., 2017b; González-Badillo & Sánchez-Medina, 2010; Sánchez-Medina & González-Badillo, 2011a). However, to date, limited literature exploring the use of such a relationship as a means to dictate load in real-time exists. Alternatively, research has focused on the velocity as the independent variable, comparing maximal velocity lifting to various other sports specific and half-velocity interventions (González-Badillo et al., 2015; Negra et al., 2016; Ramírez et al., 2015). While such methods have documented significant improvements in various outcome variables, the use of velocity in this manner offers no additional benefits with respect to the previously outlined limitations of currently utilised loading methods.

As such, study 2 (chapter 5.0) of this thesis primarily sought to explore the efficacy of utilising real-time MCV as a means of dictating training load when compared to traditional percentage-based methods (section 5.3.5). In order to facilitate velocity-based loading, the use of generalised group-based LVPs were adopted, enabling training load to be modified through comparisons between an athlete's current MCV and that of the previously recorded group average (section 2.3.4). This was the first time MCV has been used in such a manner within research to date, and as such provides a novel insight into the applied aspect of such methods. The results presented within chapter 5.0 (section 5.4) demonstrate the potential benefit of adopting group-based velocity loading methods when compared to a traditional percentage-based approach. Specifically, statistically significant increases in all assessed measures of maximal strength and vertical jump height occurred following the VBT intervention when compared to the PBT group. This finding is furthered considering the significant reduction in total training volume completed by the

velocity-based intervention over the full programme. While only bench press resulted in a significant group by time effect ( $F_{(1,14)} = 11.50, p = 0.004$ ), the velocity-based intervention did result in a greater magnitude of change over time across all variables when compared to the percentage-based approach (back squat: 9.3% vs. 8.4%; bench press: 8.4% vs. 4.0%; strict overhead press: 6.5% vs. 6.2%; deadlift: 6.4% vs. 3.0%; CMJ: 5.0% vs. 1.0%, respectively). As such, the VBT intervention resulted in greater ES and magnitude-based inferences for all tested variables.

Despite the positive contribution of this novel data to the current literature surrounding the use of velocity-based loading methods, the limitations within chapter 5.0 need to be acknowledged. Specifically, while the velocity-based loading intervention resulted in positive improvements in measures of muscular strength and power when compared to PBT, the presence of large between participant variability may have affected the efficacy of such a loading method. As previously discussed (section 5.6.1; Figure 13), the individual LVP can vary significantly, independently of relative or absolute strength values. While early research demonstrated the strength of the LVP both within and between participants (González-Badillo & Sánchez-Medina, 2010), the current data collection suggests otherwise. As such, the potential for individual participants to fall outside of the group-based mean, and thus be higher or lower than the velocity zone at a given relative percentage is increased. Such occurrences would potentially lead to suboptimal load prescription, impacting upon the efficacy of such an approach. While technically the collected MCV values would correct themselves during the warm-up sets, such an occurrence would impact upon the completed volume to prescribed volume ratio. Within the current study, following collection of all LVP data and creation of velocity zones, the group profiles for each movement were visually

inspected to delimit the likelihood of this occurring. Despite this, research should explore the efficacy of adopting individualised profiles as a means to remove the chance of such issues.

Consequently, the final study within this thesis was designed to explore the use of individualised LVPs in comparison to a generalised group-based approach in a strength trained population. It was hypothesised that the use of such individualised profiling may reduce the error witnessed, increasing the specificity of loading and thus the effectiveness of the programme. As such, greater physical adaptations would be witnessed when compared to a more generalised approach. Furthermore, as the target repetition velocity zones are based on the individual athlete's profile, the target training volume should be achievable. As previously mentioned, the efficacy of such innovative loading methods has not currently been explored, and as such the original data reported within this chapter contributes significantly to the current knowledge surrounding applied VBT methods. Specifically, the reported results provide additional evidence on the effectiveness of velocity-based loading interventions, and further increase the confidence around utilising such approaches when aiming to improve measures of lower body strength and power (González-Badillo et al., 2015; 2014; Negra et al., 2016; Pareja-Blanco et al., 2014; 2017). The data displays how integration of individual velocity-based load prescription may create a favourable environment over generalised group-based approaches, and potentially more traditional percentage-based methods. While all assessed variables significantly improved pre- to post-intervention for the ILVP group ( $p < 0.01$ ), only the back squat, CMJ, and SSJ improved for the GLVP intervention ( $p < 0.05$ ). Furthermore, the magnitude of improvements were greater for the ILVP group when compared to the GLVP group over time (back squat: 9.7% vs. 7.2%; CMJ:

6.6% vs. 4.3%; SSJ: 4.6% vs. 4.3%; SBJ: 6.7% vs. 3.3%, respectively). Despite this, no significant group by time interactions were recorded for any of the measures assessed, although back squat and SBJ demonstrated trends approaching significance ( $F_{(1,17)} = 3.97$   $p = 0.06$ ; SBJ:  $F_{(1,17)} = 3.49$   $p = 0.08$ , respectively). While the lack of statistical significance between groups over time does need to be highlighted, the greater magnitude of change, larger ES, and stronger magnitude-based inferences across all variables does suggest utilising an individual velocity-based loading approach may provide a favourable environment for adaptation.

As previously discussed, the adaptations and improvements consequent to resistance training are largely determined by the periodic arrangement of the acute training variables (Kraemer, 1983a, 1983b). While all of the variables contribute to the overall magnitude of change, research has demonstrated the importance of training intensity with regards to strength and power (Jenkins et al., 2015; Schoenfeld et al., 2015b). The external load combined with the contraction velocity ultimately equate to the force applied through the muscle, which directly impacts upon the recruitment of required motor units (Jenkins et al., 2015). As such, it could be theorised that as load is fixed throughout a working set, velocity is the key variable with regards to optimal force generation. Thus, manipulating load and repetitions based on preceding velocity output may enable athletes to maintain higher force outputs over periodised training.

In a similar way to that of chapter 5.0, the use of MCV as a load dictating variable within chapter 6.0 may have positively impacted upon the recruitment of higher threshold motor units (Desmedt & Godaux, 1977; Nardone et al., 1989). Within chapter 6.0 specifically, while both training interventions were based around velocity

dictated load, only the ILVP groups loading was specific to their individual LVP. Due to data previously reported (section 5.6.1), it can be theorised that this would have led to a greater specificity of load when compared to the GLVP approach. While chapter 5.0 specifically demonstrated the potential benefit of utilising a generalised group-based loading approach over percentage-based loading, it may not be as sensitive as an ILVP approach. This could potentially explain the variance in the assessed variables reported. Ultimately, prescribing and modifying training load based on ILVP offers a greater sensitivity specific to that of the individual, as such, higher velocities can be maintained throughout repetitions, increasing overall force output and thus motor unit recruitment.



## **8.0 Conclusion and future research**

## **8.1 Conclusion**

Taken collectively, the research studies that are presented within this thesis provides preliminary data supporting the use of velocity-based loading interventions when working with trained individuals. The results first demonstrate how MCV can be tracked reliably over time and used to accurately prescribe optimal relative training loads in real-time across a range of extensively practiced multi-joint movements. Furthermore, prescribing load based on attained MCV leads to significant increases in measures of maximal strength and power when compared to a traditional percentage-based approach, despite a potential for less required training volume. While no significant difference was present between group- or individual-based approaches, the marginal improvements witnessed following ILVP compared to GLVP may suggest a greater potential for adaptation when such an approach is adopted. As such, this thesis serves to demonstrate that monitoring MCV within resistance training offers a more objective and sensitive approach to prescribing training load than traditional percentage-based approaches. These findings and the further questions they present warrant further research in this area, specifically exploring the efficacy of obtaining the LVP and uses of the individualised approach.

### **8.1.1 Recommendations for future practice for the use of VBT within strength and conditioning**

The two intervention studies within this thesis demonstrate the potential benefits of adopting a velocity-based loading approach over traditional percentage-based methods. Furthermore, with specific reference to study 2 (chapter 5.0), the use of generalised group-based LVPs may lead to a reduction in the total training volume required to see these adaptations. As such, this novel training approach could be

adopted during all blocks within a competitive season, reducing the likelihood of unnecessary training volume. This has potential positive implications for team sport athletes, or those with a long competitive season, as generally during such training periods volume will be reduced to minimise fatigue and keep athletes in a good state of physical readiness. Strength and conditioning professionals adopting such a loading approach (as in chapter 5.0 and 6.0) would be able to facilitate objective loading based on individualised performance variables which have been shown to be linked to daily fluctuations in biological status and readiness to train (Pareja-Blanco et al., 2014; Sánchez-Medina & González-Badillo, 2011a). Therefore, it could be assumed that adopting a velocity-based loading approach may aid in athlete fatigue monitoring and reducing stress commonly induced by resistance training, increasing not only the efficacy of training sessions, but also competitive games/events throughout.

Further to this, as demonstrated within both interventions, velocity-based loading approaches may complement traditional loading methods, overcoming the shortcomings associated with subjective load alterations and prescription based on pre-training 1-RM. For velocity-based measures to be successful it should be acknowledged that they are not suitable for all movements, hence the mix of loading approaches adopted during both study 2 and 3 (chapter 5.0 and 6.0). However, as demonstrated, such an approach has the capacity to advance training through accurate prescription of optimal relative load increasing the efficacy of training over time. Specifically, the concept of velocity-based loading appears to integrate well into more traditional multi-joint compound movements such as the back squat, bench press, deadlift, and prone bench pull. Due to the linear movement patterns of such exercises, recorded displacement is generally free from additional noise/error,

increasing the validity and reliability of subsequent derivatives (chapter 4.0). While this is the area current literature has focused on, devices such as the GPT do contain sophisticated systems able to detect the angle of the tether during a given movement and factor this into subsequent calculations. As such, while current literature has not focused on such movements, the GPT, and specifically velocity-based loading, could be integrated effectively across more movements including Olympic weightlifting and derivatives.

A point of consideration with regards to this revolves around the impact of the external load on the reliability of displacement and subsequent derivative outputs. As previously discussed (section 4.5), the attachment site of devices such as the GPT has the capacity to impact upon the validity and reliability of the outputs. As relative load is decreased, the potential for horizontal sway of a bar during more explosive movements is increased. As such, there is potential for the end of the bar (generally where the GPT is attached) to displace at a greater or lesser rate than the centre. As such, it could also be theorised that data at the lower spectrum of 1-RM will be more susceptible to collection error. Previous literature has also alluded to such things, demonstrating an increase in validity of outputs as relative loading is increased (Crewther et al., 2011b). As such, care should be taken when utilising LPTs, specifically within regards to the attachment site and the relative load and explosiveness of the movement.

Additionally, the ease of use of devices such as the GPT, and the fact they operate an online cloud-based data storage system, means strength and conditioning coaches and athletes can access both past and real-time data at any stage throughout a training cycle. This not only assists in the tracking of performance

variables over time but enables feedback to be provided to coaches and athletes in real-time without the need for their presence. Using such devices provides athletes with the ability to autoregulate training, based on real-time objective feedback, outside of the coaching environment. Furthermore, the coach can view this feedback, and the changes the athlete makes as they occur, enabling subsequent sessions to be progressively programmed. In addition to this, the GPT specifically automatically runs the displacement data through the full process of differentiation, and as such records all available derivatives. While strength and conditioning coaches may initially only focus on one variable, such as MCV, the data for all variables is stored for all repetitions. This means that if the coach or athlete wish to explore further aspects of performance such as relative force or power, the data will be available for all previous repetitions completed over an indefinite time period.

As a final application, data pertaining to the efficacy of the GPT is also presented within this thesis. The GPT has demonstrated the sensitivity required to be able to implement such approaches as described within this thesis within a strength and conditioning environment. The device and cloud-based storage system offer coaches and athletes a range of benefits as previously highlighted enabling the optimisation of training sessions and programming based on objective performance variables. Furthermore, as the GPT provides real-time feedback on these variables, coaches and athletes obtain additional avenues for motivation. Numerous researchers have shown the benefit to performance through utilisation of kinetic and kinematic feedback received from such devices (Randell et al., 2011; Weakley et al., 2017; 2018). As such, not only does the process of manipulating load on velocity positively impact the training variable outcome, but the use of real-time feedback

within the training environment will increase the efficacy of the training session as a whole.

## **8.2 Limitations**

When interpreting the current results, it is important to highlight and acknowledge the limitations associated with the research projects presented within this thesis.

- i. Firstly, it must be acknowledged that while the participants used throughout all three data collections were from a resistance trained background, and thus allow a greater transferability of the findings to the athletic development, the sample sizes were relatively small, leading to potentially underpowered results. In an attempt to delimit this, the use of effect sizes and inferential statistics were used, providing readers with an appreciation of the findings irrespective of participant numbers. Furthermore, for each further study the participant numbers did increase in an attempt to demonstrate an attempt to alleviate this concern.
- ii. The LVP approach implemented during both study 2 and 3 (chapter 5.0 and 6.0) was time consuming due to the novel aspect of collecting all data points within the profile (~ 1 hour per participant). While this provided the complete data set required, removing the need to estimate data points within the LVP, it was considerably more time consuming and thus not truly reflective of applied strength and conditioning practices. Such an approach was adopted to remove the concern previously discussed surrounding the collection and estimation of LVPs within contemporary literature.

- iii. Within study 2 specifically (chapter 5.0), only the VBT intervention received feedback specific to the velocity of their completed repetitions. The comparison group (PBT) received general encouraging feedback, however this was not objectively based on their achieved velocity. It is worth noting that contemporary literature exploring the use of such feedback has demonstrated minimal differences between performance when either verbal kinematic or verbal encouragement are given suggesting the likely impact of this limitation was minimal (Weakley et al., 2018). However, as velocity-based feedback was only given to the VBT group, it may have trivially impacted upon the overall difference noted pre- to post-intervention. In an attempt to remove this concern, chapter 6.0 standardised the feedback, with both groups receiving both verbal encouragement and auditory kinematic feedback.
- iv. In additional reference to study 2 (chapter 5.0), MCV was only recorded for the VBT intervention group. As such it can only be assumed that the PBT group were lifting maximally during each repetition. Furthermore, volume could only be calculated via traditional methods for the PBT group, utilising pre-training 1-RM, as opposed to the “actual” relative load participants were lifting at as with the VBT group. This additional information may have provided a deeper understanding as to why the VBT intervention led to the greater improvements reported, as well as the lower reported volume. While this is the case, participants were provided with strong verbal encouragement throughout to ensure lifting velocity was maximal, however as no data were recorded it can only be speculated.

- v. Study 3 (chapter 6.0) attempted to delimit both of the previously highlighted limitations by recording and providing both intervention groups with MCV feedback in real-time. However, the removal of a true comparison group at this stage (PBT approach) means the transferability of the results and conclusions are limited. The fact the comparison group within this collection (GLVP) followed the same method as the intervention group within study 2 (chapter 5.0) which was compared to a PBT approach does delimit this concern slightly, however the use of a “true” comparison within the form of a PBT group would have enabled stronger conclusions to be drawn.
- vi. A final point of acknowledgment is that at no point during this thesis were measures of muscular or neural adaptations measured, or athlete perceptions of training fatigue collected. As such, the mechanisms responsible for the witnessed physical improvements in measures of strength and power can only be theorised at this stage.

### **8.2.1 Directions of future research**

While the reported data and subsequent conclusions present a significant and novel contribution to the existing literature surrounding VBT, they also provide clear avenues for future research to further strengthen the understanding of such a training method. Given the limited body of literature surrounding the efficacy of such loading approaches, there are a number of interesting avenues worthy of future research to explore.



Firstly, it should be acknowledged that the method by which the LVP is obtained has yet to be explored within the literature (previously discussed within section 2.3.3.1). Within the current thesis a full profile was collected within both intervention studies, with participants completing an average of fifteen sets. However, contemporary literature generally adopts a significantly reduced approach, collecting only four to five data points before extrapolating the remaining data set once the equation of the line is known (Banyard et al., 2017a; Conceição et al., 2016; Loturco et al., 2017; Picerno et al., 2016). While this method is less time consuming, and thus offers better transferability and applicability to the applied setting, the reliability and validity of such approaches is yet to be explored. As such, future research should endeavour to establish the efficacy of different methods of obtaining the LVP, ultimately providing a standardised approach for all future research to follow. Such methods could attempt to integrate further testing approaches, such as the calculation of minimum velocity threshold, as a means to avoid taking athletes to true 1-RM (Izquierdo et al., 2006a). This would not only assist within the applied setting, but also strengthen future comparisons as data would be collected using the same approach.

Once a reliable method of profiling is established, research should explore and determine the load-velocity relationship of additional commonly practiced movements. While widely utilised “strength training” exercises, such as the back squat, bench press, and military press have been explored within the literature (Balsalobre-Fernández et al., 2018a; Conceição et al., 2016; Sánchez-Medina et al., 2017), to date, limited data relating to Olympic weightlifting movements and derivatives is available. Such movements are advocated throughout literature as an effective means to improve force and power production (Hoffman, Cooper, Wendell,

& Kang, 2004; Suchomel, Comfort, & Lake, 2017; Teo, Newton, Newton, Dempsey, & Fairchild, 2016; Tricoli, Lamas, Carnevale, & Ugrinowitsch, 2005), and as such it could be theorised that combining them with velocity-based loading approaches would lead to augmented adaptations. As such, future research should explore the efficacy of LVPs within Olympic weightlifting movements, and further investigate whether such profiles can be used to prescribe relative load in real-time. Additionally, an exploration of the effectiveness of such velocity-based loading methods against those more traditionally practiced within Olympic weightlifting would further the understanding surrounding this novel loading concept.

Study 3 (chapter 6.0) explored the impact of individualising load prescription based on individualised LVPs. While the data presented suggests only trivial improvements will be witnessed when compared to a group-based LVP approach, this was the first study to explore such a method. As such, future research should continue to document and investigate the individual differences present between participants LVPs and attempt to understand how these may be manipulated to potentiate greater adaptations to training. Such research would initially establish the likely magnitude of individual differences present between different level athletes, before exploring additional mechanistic measures outside of the scope of this thesis. As an example, while 1-RM was considered the dominant outcome variable within this thesis across studies, future research exploring individualised VBT should explore skeletal muscle velocity capabilities at various submaximal loads. Such research would strengthen the understanding surrounding adaptation following such loading methods and demonstrate additional benefits outside of maximal strength.

As previously highlighted, one of the potential limitations within this thesis is the lack of understanding regarding the mechanisms of change following a velocity-based loading intervention. While such data collection was outside of the aims of this thesis, which instead focused on the magnitude of change following such loading strategies, future research should endeavour to explore and highlight the key muscular, neural, and perceptual changes that collectively facilitate the adaptations witnessed. Such research would provide a greater understanding of how utilising velocity-based loading methods impact upon the athlete and would allow more precise programmes to be developed, strengthening to potential for positive adaptation.

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## **10.0 Appendices**

## **10.1 Appendix 1: Example participant information sheet**

**Study Title:** Comparison of individual and group-based load-velocity profiling as a means to dictate training load over a six-week strength and power intervention

You are being invited to take part in a research project. Before you decide to participate it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask if anything is unclear or if you would like more information.

### **What is the purpose of the study?**

The purpose of this study is to investigate the effects of the inclusion of individualised velocity-based training zones within a resistance training programme over a single mesocycle (six weeks). This will be achieved via a direct comparison to a traditionally designed velocity-based training programme, utilising generalised group-based mean velocity data.

### **Why have I been invited?**

As you currently participate in exercise beyond a recreational level you will be familiar with the demands associated with the types of tests and training involved. Furthermore, you will have a good understanding as to the correct technique required. Previous training experience will enable less effect to be felt from the testing / training protocol itself, increasing intersession reliability.

### **What would be involved for me?**

You will be required to complete several forms detailing your ability to participate in the study as well as training history. Following review of these you will complete a series of familiarisation trials to make sure you understand the protocols fully and can maintain required technique, prior to initiation of testing / training.

All familiarisation, testing, and training will take place within the Strength and Conditioning laboratory, located within the Human Performance Centre, University of Lincoln. Familiarisation will include working up to your one repetition maximum in



back squat as well as a series of jump assessments, including countermovement, static squat, and standing broad jump.

At this stage you will be randomly assigned to either an individual velocity-based group, whereby the resistance you lift within each session will be individualised to you and dictated by the velocity at which you can complete the given movement. Alternatively, you will be assigned a traditional velocity-based group, whereby the resistance you lift within each session will be based on the group mean data and dictated by the velocity at which you can complete the given movement. Both of these methods are scientifically underpinned, and both programme designs will be released to all participants upon request following completion of the investigation.

Once pre-intervention data has been collected you will be required to attend a training session twice a week (for six weeks; days can be negotiated but require adequate rest time between). Sessions will be based around lower body strength and power. For each session you will be required to complete a series of sets and repetitions of back squat, Romanian deadlift, and countermovement jumps, as well as a range of lower body assistance exercises including walking lunges, leg press, hip thrusts, etc. Throughout the six-week programme, the volume of the exercises will decrease, and the intensity will increase. Both groups will be completing the same programme, however as repetitions and load are being calculated via different methods, you may end up deviating from the programme if you cannot maintain the desired velocity.

Following six weeks of training, you will be required to come to the labs one final time, to re-test your one repetition maximum and jump assessments. The initial and final testing session will take between 1 / 1.5 hrs to ensure adequate rest is taken between each trial and test. Each subsequent training session will take approximately 1 hr.

### **What are the possible benefits of taking part?**

All personal results will be made available to you upon request once all data collection has been completed enabling you an insight into your own levels of fitness across varying components. Furthermore, both training programme designs will be released to all participants upon request. The overall aim is to add this study to the

research required to complete a PhD, with the aim of hopefully publishing. Participation in such a study will provide an insight into the effect velocity-based training has on strength and power adaptations, providing information directly relating to strength and power adaptations.

**What are the possible disadvantages and risks of participation?**

There is a risk of injury occurring due to the nature of the testing and training protocol, however full supervision will be provided throughout all stages as well as familiarisation trials to ensure correct technique is adopted. Risk assessments have been carried out to minimise risks, and all participants will be required to complete a warm-up prior to taking part in any of the testing / training.

**What do I need to do if I wish to take part?**

Your participation in this study is entirely voluntary. If you do decide to participate, you have the right to withdraw from the study at any point.

Please read this information sheet and ask any questions that you may have relating to the proposed study. If you still wish to proceed, then please read and sign the attached documents and finally the consent form. These will be reviewed by the investigator to ensure you meet the relevant conditions of the study, after which you will be informed either way and testing will commence.

**Will my taking part in the study be kept confidential?**

Your name will not be revealed in any report or publication, and no reference will be made which could link you to the study. Images of you will not be used in reports or presentations without your explicit permission. All data collected will be handled in strict confidence and will be seen only by the investigator and project supervisors. Following completion of the research, and once work has been presented / published, all data will be destroyed to ensure complete confidentiality (data will be held for a maximum of three years following publication or presentation).

**Further information:**

Once all data has been collected for all participants, and data analysis has been completed, you are entitled to request any data collected on yourself for your own records, as well as the programme design and template used.

**What if I have any concerns or queries?**

For issues relating to the project, please contact either the lead researcher: Harry Dorrell, **[HDorrell@lincoln.ac.uk](mailto:HDorrell@lincoln.ac.uk)**, 01522 886680 or the project supervisor: Dr Thomas Gee, **[TGee@lincoln.ac.uk](mailto:TGee@lincoln.ac.uk)**, 01522 837143.

If you would like to talk to someone about ethical issues relating to the project, please contact Dr Danny Taylor (**[DTaylor@lincoln.ac.uk](mailto:DTaylor@lincoln.ac.uk)**; tel 01522 886845) at the University of Lincoln.

Thank you for taking the time to read this information.

## 10.2 Appendix 2: Example physical activity readiness questionnaire

The purpose of this questionnaire is to ensure that you are physically able to complete the following exercise test(s). Please fill out form truthfully. All information will be treated with the **strictest confidence** and only reviewed by the research team. Thank you for your cooperation.

Please **CIRCLE** the most appropriate option and use **BLOCK CAPITALS** when providing further detail.

**Participant code:** \_\_\_\_\_

**Date:** \_\_\_\_/\_\_\_\_/\_\_\_\_

**How would you describe your present level of activity?** ( \_\_\_\_ times a week)

- (a) Sedentary
- (b) Moderately active
- (c) Active
- (d) Highly Active

**How would you describe your present level of fitness?**

- (a) Very unfit
- (b) Moderately fit
- (c) Trained
- (d) Highly Trained

**Do you smoke?**

Y / N

**If N, go to next question. If Y, is this:**

- (a) Regularly (no. per day \_\_\_\_)
- (b) Occasionally (no. per day \_\_\_\_)
- (c) Previously (no. per day \_\_\_\_) (date you stopped smoking \_\_\_\_/\_\_\_\_/\_\_\_\_)

**Do you drink alcohol?**

Y / N

**If N, go to next question. If Y, is this:**

- (a) Occasionally
- (b) Daily
- (c) More than one drink a day

**Have you consulted your doctor within the last 3 months?**

Y / N

If Y, please provide details:

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---

**Are you presently taking any form of medication?**

Y / N

If Y, please provide details:

---

---

**Do you suffer, or have you ever suffered from, any of the following?**

Asthma:	Y / N
Diabetes:	Y / N
Bronchitis:	Y / N
Epilepsy:	Y / N
High blood pressure:	Y / N

If Y, please provide details:

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**Do you suffer (or have suffered from) any form of heart complaint?** Y / N

If Y, please provide details:

---

---

**Is there history of heart disease in your family?** Y / N

If Y, please provide details:

---

---

**Do you currently have any form of muscle or joint injury?** Y / N

If Y, please provide details:

---

---

**Have you had any cause to suspend your normal training/activity during the past 4 weeks?**

Y / N

If Y, please provide details:

---

---

**Is there anything to your knowledge that may prevent you from taking part in practical training/testing?**

Y / N

If Y, please provide details:

---

---

### 10.3 Appendix 3: Example medical history questionnaire

The purpose of this questionnaire is to gain any information regarding any medical conditions you may suffer from which would impact upon your safety when taking part. Please fill out form truthfully. All information will be treated with the **strictest confidence** and only reviewed by the research team. Thank you for your cooperation.

Please **CIRCLE** the most appropriate option and use **BLOCK CAPITALS** when providing further detail.

**Participant code:** \_\_\_\_\_

**Date:** \_\_\_\_/\_\_\_\_/\_\_\_\_

**1. Do you have any allergies to drugs, foods, etc.?**

Y / N

If Y, please provide details:

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---

**2. Do you suffer from asthma?**

Y / N

If Y, please provide details:

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**3. Are you currently taking any medications/supplements?**

Y / N

If Y, please provide details:

---

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**4. Have you received a concussion in the past 12 months?**

Y / N

If Y, please provide details:

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**5. Have you injured your neck or spine in the past 12 months?**

Y / N

If Y, please provide details:

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**6. Have you been hospitalised or under gone surgery in the last 12 months?**

Y / N

If Y, please provide details:

---

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**7. Do you have a history of joint or muscle injuries?**

Y / N

If Y, please provide details:

---

---

**8. Have you broken a bone in the last 12 months?**

Y / N

If Y, please provide details:

---

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**9. Have you been diagnosed with a heart murmur or high blood pressure?**

Y / N

If Y, please provide details:

---

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**10. Do you have any other health issues that would place you at risk of serious injury while participating in sports?**

Y / N

If Y, please provide details:

---

---

#### 10.4 Appendix 4: Example current activity questionnaire

The purpose of this questionnaire is to gain information regarding your current level of activity within exercise and the specifics of this. Please fill out form truthfully. All information will be treated with the **strictest confidence** and only reviewed by the research team. Thank you for your cooperation.

Please **CIRCLE** the most appropriate option and use **BLOCK CAPITALS** when providing further detail.

**Participant code:** \_\_\_\_\_

**Date:** \_\_\_\_/\_\_\_\_/\_\_\_\_

##### 1. How would you describe your occupational level of daily activity?

- a) Light
- b) Moderate
- c) Heavy
- d) Intense

##### 2. How would you describe your level of planned physical activity?

- a) Light
- b) Moderate
- c) Heavy
- d) Intense

##### 3. How often do you complete physical exercise training?

\_\_\_\_\_ days per week

**4. What makes up the majority of your training?**

- a) Resistance training
- b) Cardiovascular training
- c) Skills training
- d) Flexibility training
- e) Other (please state) \_\_\_\_\_

**5. How long have you been continually training for?**

\_\_\_\_\_ months \_\_\_\_\_ years

**6. How long have you been engaging in resistance training?**

\_\_\_\_\_ months \_\_\_\_\_ years

**7. Do you consider yourself to be...**

- a) Untrained
- b) Recreationally trained
- c) Resistance trained
- d) Experienced athlete
- e) Other (please state) \_\_\_\_\_

## 10.5 Appendix 5: Example informed consent from

I agree to take part in this research project which will involve both resistance testing and training. Any information I provide will remain strictly confidential.

- The full details of the research have been explained to me and I am fully aware of what is expected of me as a participant.
- I am responsible for providing information relating to my health status and / or previous experiences of unusual sensations / reactions caused by physical activity. I am also responsible for reporting any unusual feelings or discomfort felt by myself during the study.
- I am aware that I am not obliged to complete the assessments and that I am able to stop at any point, for any reason.
- I am aware that the research results and any information I have provided are fully confidential and that no reference in any written publication or oral presentation will link me to participation in the study.
- I am not aware of any injury and/or illness that will affect my ability to perform within the study to the best of my ability.
- I am aware that my participation in this study is completely voluntary. If I decide not to participate there will not be any negative consequences. I am aware that if I decide to participate, I may choose to withdraw at any time and ask that any data collected concerning myself is destroyed.

I have read and understand the information above, and any questions that I had have been fully answered. I agree to participate in this study.

**Please circle to signify you have seen and completed the following:**

Physical activity readiness questionnaire	Y / N
Medical history questionnaire	Y / N
Current activity questionnaire	Y / N

**Name (print):** \_\_\_\_\_

**Signature:** \_\_\_\_\_

**Date:** \_\_\_\_/\_\_\_\_/\_\_\_\_

I declare that I have reviewed this form and have made myself available for any questions the participant may wish to ask.

**Signature of researcher:** \_\_\_\_\_

**Date:** \_\_\_\_/\_\_\_\_/\_\_\_\_

## 10.6 Appendix 6: Example inclusion criteria document

Participant code: \_\_\_\_\_

Date: \_\_\_\_/\_\_\_\_/\_\_\_\_

**If the answer to the following is 'N', exclude:**

Is the participant male, and between the age of 18-40?

Y / N

Age: \_\_\_\_\_

**If the answer to any of the following is 'N', exclude:**

Has the participant been engaged in resistance training for at least 2 years, with 6 months continuous training prior to this date?

Y / N

Is the participant familiar with the testing/training protocols they will be required to complete for the research?

Y / N

**If the answer to any of the following is 'Y', exclude:**

Is the participant:

Currently suffering from any musculoskeletal injury or disorder?

Y / N

Currently suffering from any cardiorespiratory injury or disorder?

Y / N

Currently suffering from any injury or disorder that requires the use of medication that may affect their ability to perform exercise?

Y / N

Currently suffering from any impediment that may affect their safety / wellbeing during the testing / training?

Y / N

Currently taking any performance enhancing substances?

Y / N

Currently suffering from any form of chest pain while completing exercise?

Y / N

**If the answer to the following is 'N', exclude:**

Has the participant completed all questionnaires and signed the consent form?

Y / N

---

☐ **Inclusion**

☐ **Exclusion**

I declare that I have reviewed this form and have made myself available for any questions the participant may wish to ask.

**Signature of researcher:** \_\_\_\_\_

**Date:** \_\_\_\_/\_\_\_\_/\_\_\_\_